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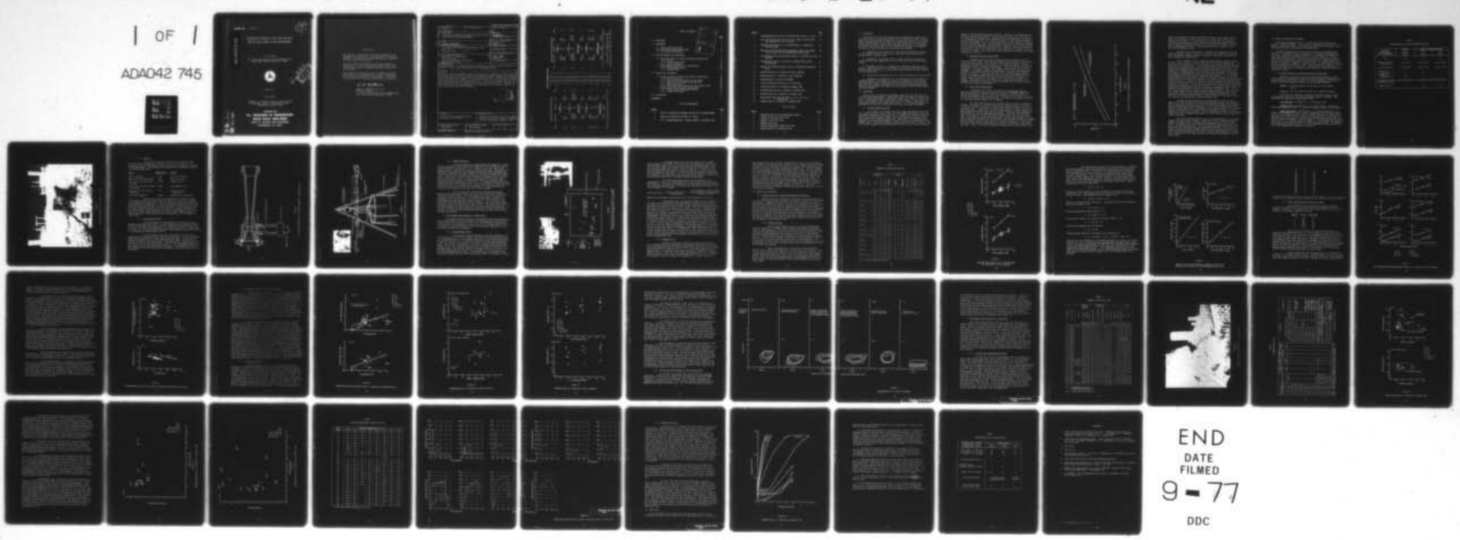

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EVALUATION OF NOZZLES TO BE USED WITH AFFF AND THE COAST GUARD IN-LINE PROPORTIONER

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16. Abstract

Evaluative, fire extinguishment and burnback tests were conducted at the USCG Fire and Safety Test Facility, Mobile, Alabama, to determine the optimum nozzle to be used with the CG-6LP proportioner and Aqueous Film Forming Foam (AFFF). Commercially available water fog nozzles were compared to the mechanical foam nozzle and the Navy all purpose nozzle currently in use on Coast Guard cutters. The water fog nozzles produced the best range and offered more versatility in the patterns they produced. The best two water fog nozzles and the mechanical foam nozzles were able to control a 660 sq. ft. JP-5 deck fire in less that 25 seconds.

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METRIC CONVERSION FACTORS

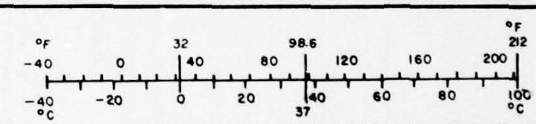
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1.0 OBJECTIVES

The objective of this test program was to determine the optimum nozzle to be used with the in-line proportioner by the Coast Guard fleet. The combinations must be suitable for use with 6 percent AFFF (aqueous film forming foam). Systems using 3 percent AFFF were also evaluated as an alternative. In choosing a nozzle for the system, consideration was given to its adaptability for use on hose lines in closed spaces and on deck. To accomplish the above, the following specific objectives were addressed:

1. Determine if the present Coast Guard in-line proportioner produces or can be simply modified to produce an acceptable foam solution using 6 percent AFFF or 3 percent AFFF.

2. Determine if the present Navy All Purpose nozzle will produce an acceptable AFFF foam blanket when used with the Coast Guard in-line proportioner.

3. Determine if there is a commercially available nozzle which would produce a significantly better foam blanket or offer other superior features when used with 6 percent or 3 percent AFFF proportioned by the Coast Guard's in-line proportioner.

4. Verify that non-aerated AFFF is at least as effective as aerated AFFF.

5. Determine the capabilities and characteristics of the optimum foam systems developed in this program. Specific characteristics will include foam application rates, minimum foam application densities to prevent burnback, flow and pressure requirements for the system, and maximum permissible pressure losses between the proportioner and nozzle in terms of hose lengths and nozzle heights.

2.0 BACKGROUND

Over the past few decades low expansion foams have been very effective as fire extinguishing agents. Their primary use is on Class "B" fires, which occur on Coast Guard vessels in machinery spaces, paint lockers, flight decks, etc. A low expansion foam system requires a water supply, a foam supply, a proportioning device and an application nozzle. It is the proper design and maintenance of the entire system which produces the successful package.

2.1 Protein Foam Versus AFFF

The original low expansion foam which came into general use by the Coast Guard was protein foam. There are still large quantities of this foam concentrate throughout the operating fleet. However, as the protein foam is used, it is being replaced by AFFF. AFFF was developed by the Navy and has some superior fire fighting capabilities. When used in low expansion foam systems, it provides extinguishment of Class "B" fires much more rapidly than protein foam. It also has a degree of effectiveness for Class "A" fires. One of its most frequently voiced deficiencies is that it has a low fire securing

ability thus permitting unexpected reflashes. AFFF has a few characteristics different from protein foam which must be designed around. The viscosity of 6 percent AFFF is approximately 5 centistokes at room temperature and increases to 15 centistokes at 25°F. The maximum viscosity of protein foam is approximately 89 centistokes at 32°F. The primary effect of this viscosity difference lies in proportioning. Most in-line proportioners can be modified by changing the foam orifice to properly proportion AFFF. AFFF also has a corrosive effect on many metals and materials when permitted to remain in contact with them for long periods of time. This deficiency can be overcome by the proper choice of materials for tanks, lines, proportioner and nozzles and by flushing all systems subsequent to foam use.

2.2 Non-aerated Versus Aerated AFFF

Mechanical aeration of fire fighting foams was developed with the advent of protein foams. When AFFF was brought into existence, it was aerated as a matter of procedure. Navy testing[1,2] has shown that special nozzles designed to produce mechanical aeration are not always necessary for producing an acceptable AFFF fire fighting foam blanket. This has some very obvious advantages. In the first place, a non-aerated foam requires less specialized equipment. For example, standard fire fighting hose nozzles used throughout the ship could also be used with the AFFF system. Aeration also produces a fluffy foam similar to soap suds which does not have good throwing characteristics. A non-aerated AFFF could be used to eliminate this deficiency. A certain amount of aeration is required, however, to develop a visible foam blanket. The importance of this blanket is to permit the firefighter to determine what areas of the fire he has secured and to give him the confidence to carry on with his extinguishment.

2.3 Coast Guard Foam Systems

A prototype fixed system consisting of a foam storage tank and balanced proportioner has been installed on board CGC MORGENTHAU (WHEC 722). This system supplies a 6 percent AFFF foam solution to the twin agent unit located in the engine room, to the re-entry stations for the engine room, and to the flight deck for use with hand lines. It supplies the solution at 95 GPM flow over the pressure range of 80 to 125 PSIG.

All other Coast Guard cutters and boats are fitted with "portable" systems. The reason for providing the portable systems is based on the desire to provide a portable, universal, reliable, and effective system at the most economical cost. To this end, an in-line proportioner was chosen for its principle advantages of being light and thus easily portable, of simple design and thus rugged and reliable, and reasonably priced. The proportioner-designated LP-6CG (Stock No. CG 4210-G00-1200) was designed to work over the operating range of the majority of the fire pumps in use on Coast Guard vessels at that time. This range was between 65 and 100 PSIG. When pressures within this range were provided at the inlet of the LP-6CG, it would correctly proportion 6 percent protein foam and provide a flow rate as illustrated in Figure 1. The pressure drop across the LP-6CG is approximately 35 percent of the pressure supplied at the inlet. Thus, if a cutter's fire pump provided 100 PSIG at the inlet, there

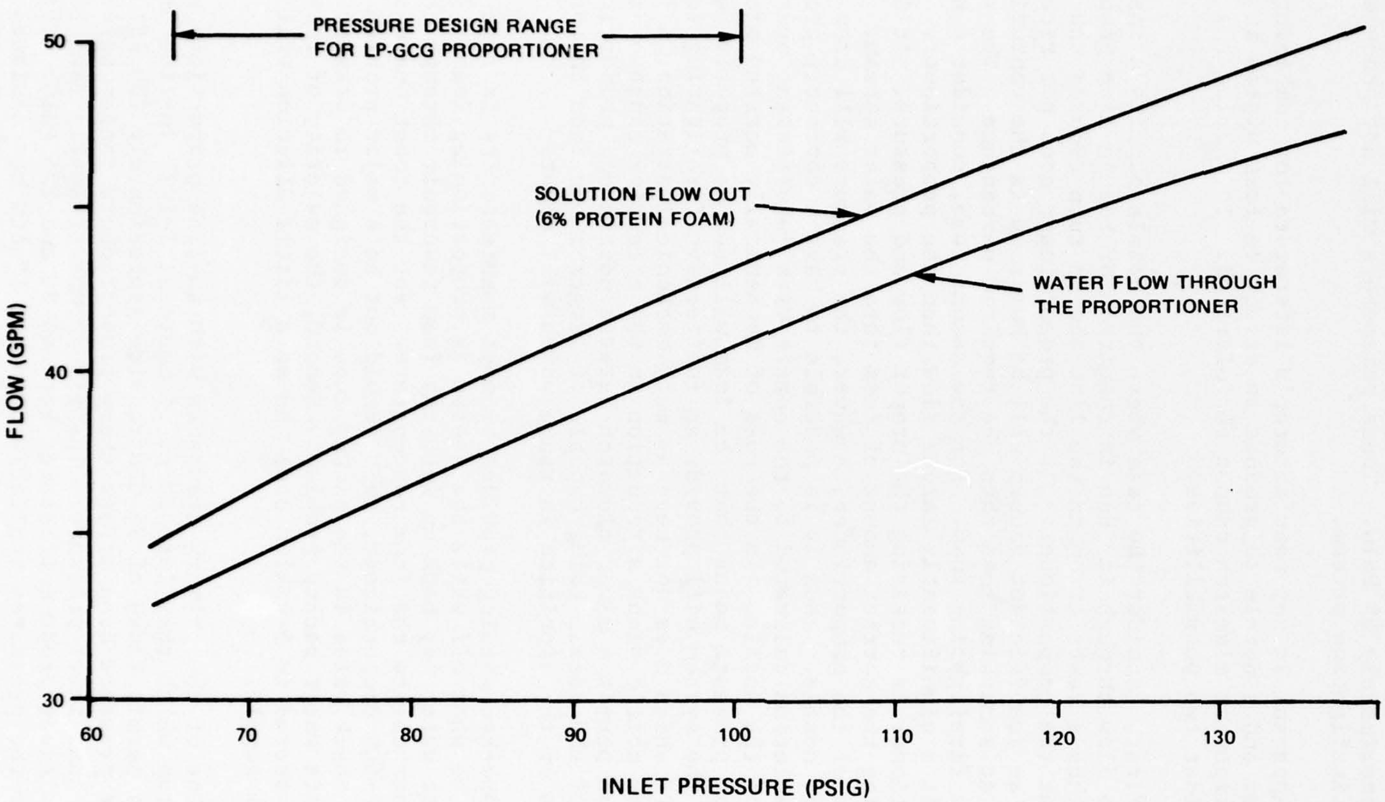


FIGURE 1

FLOW AS A FUNCTION OF PRESSURE FOR THE LP-6CG PROPORTIONER

would be approximately 65 PSIG pressure and 41 GPM of water plus 2.5 GPM of foam (i.e. 6 percent of 41 GPM = 2.5 GPM) for a total of 43.5 GPM flow of solution at the outlet. If a pressure loss of 10 PSIG due to a combination of hose friction and head losses occurred between the proportioner and the nozzle then the firefighter would have at his disposal 43.5 GPM of foam solution at approximately 55 PSIG. These parameters will not produce a very effective firefighting stream.

Apparent in any manufacturer's literature for combining an in-line proportioner and a nozzle to produce an effective foam system is the warning that the slightest mismatch cannot be tolerated. To examine the reasons for this, consider two possibilities:

First, consider the case where the nozzle permits a smaller volume of water to flow through it than is required for the in-line proportioner. The nozzle is thus a restriction in the line and in turn reduces the flow which is available at the proportioner. If the proportioner does not receive sufficient water flow an insufficient vacuum will be built up in the venturi and it will proportion at something less than the required percentage. The result is an ineffective firefighting foam. For the second case, consider a nozzle which would permit a significantly larger flow than the proportioner. In this case the proportioner is receiving the proper flow and pressure. It is, therefore, proportioning the correct amount of foam into the water stream. On the downstream side of the proportioner, however, the pressure will drop severely because of the large nozzle. Thus it is possible to have a correctly proportioned foam and water solution delivered to the nozzle with insufficient pressure for proper operation of the nozzle. In the case of mechanically aerated protein foams, this insufficient pressure means that the foam will not be properly aerated and consequently, the system will provide an ineffective firefighting foam. In the case of AFFF which does not need as much mechanical aeration, a lack of pressure at a regular nozzle means a reduction in the effective range of that nozzle. Thus one can permit a minor mismatch between nozzle and proportioner in the direction of the nozzle being capable of larger flows than the proportioner if he is aware of the sacrifice in range which will occur.

Another warning provided by most manufacturers is that the nozzle should not be shut off while the system is proportioning foam. The reason for this is that water may back up into the foam reservoir through the foam pickup tube and thus dilute the foam concentrate. For the Coast Guard's application with the LP-6CG proportioner, this should not be a major problem for two reasons. First, the check value in the pickup tube is designed to prevent or at least minimize this water backup problem. Second, the majority of foam on Coast Guard vessels is stored in 5-gallon cans and so a little dilution will not affect the entire foam supply.

One of the primary drawbacks with in-line proportioners is the large pressure drop which they introduce. Commercial 1-1/2" in-line proportioners designed to permit flows of 95 GPM require approximately 200 PSIG at their inlet. The pressure drop across these proportioners ranges between 35 and 50 percent of that inlet pressure. The fire pumps presently used throughout the Coast Guard fleet produce pressures between 80 and 125 PSIG. This is an increase over the pressures available when the LP-6CG was designed but it still does not approach the pressure required for proper proportioning for a 95 GPM flow. That rate of flow from the LP-6CG would require approximately 540 PSIG at the inlet.

3.0 TESTING APPROACH AND PROCEDURES

Testing was conducted at the U. S. Coast Guard Fire and Safety Test Facility in Mobile, Alabama. Fire testing was conducted aboard the T/V A. E. WATTS at Little Sand Island. This vessel was fitted with the necessary fire containment barriers, fire mains and instrumentation.

Two AFFF concentrates (3 percent and 6 percent) were compared during these tests to determine whether one displayed a significant advantage over the other. Preliminary analysis showed that the spreading coefficients for both concentrates were similar[6] and that the cost per gallon of the foam/water solution was similar. The principal advantage of 3 percent concentrate was that for similar foam solution capacities, half the storage weight and volume was required as compared to 6 percent AFFF. If storage space is not a factor, then twice the capacity of foam concentrate would be supplied by using the same storage as for 6 percent AFFF. The principle characteristics of 6 and 3 percent AFFF and the 6 percent protein foam used in the test series are presented in Table 1.

3.1 Evaluative Tests of Proportioner/Nozzle Combinations

Because of the desire to keep the retrofitting expenses of Coast Guard vessels to a minimum, the tests were approached with the assumption that the LP-6CG proportioner would remain as one of the components of the final system. With this assumption in mind, two options were evaluated:

Option 1 - Pair the modified LP-6CG with the CG all purpose nozzle.

Option 2 - Pair the modified LP-6CG with a commercial nozzle.

The evaluative tests were conducted as outlined in Table 2 which also summarizes the data. Specific measurements made are indicated. The procedures for making these measurements follow:

FOAM EXPANSION - Per NFPA 4.2, p. 20, Section A-230

DRAINAGE TIME - Per NFPA 412, p. 22, Section A-250. The article, "Refractory Analysis of AFFF," 5, describes the same procedure in more detail.

RANGE AND PATTERN - Per NFPA 412, p. 24, Section A-260 and p. 25, Section A-300 modified for motion picture documentation of results as follows. In place of the stakes laid out on 3-foot centers (see NFPA 4.2, Figure 7E) a grid pattern of lines on 3-foot centers will be painted on the deck over the expected foam ground pattern. This grid pattern was located on the after tank deck of the T/V A. E. WATTS as shown in Figure 2. A movie camera was placed on the 02 deck of the after deck house to record the foam patterns. All measurements were made from these movies. All tests employed one 50-foot section of 1-1/2" hose between the proportioner and nozzle.

TABLE 1

CHARACTERISTICS OF FOAM CONCENTRATES TESTED

FOAM TYPE CONCENTRATION MFG & DESIGNATION	PROTEIN 6% NATIONAL REQ	AQUEOUS FILM FORMING FOAM	
		6% 3M FC-206	3% 3M FC-203
PH	7.3	8	8
Maximum Viscosity (centistokes)	8.9 @ 32°F	4.8 @ 40°F	16.3 @ 40°F
Specific Gravity	1.140 @ 60°F	1.012 @ 77°F	1.055 @ 77°F
Minimum Use Temperature °F	20	35	0
Maximum Use Temperature °F	120	-	-
Recommended Storage Container Material	Steel/Polyethylene	Stainless Steel/PVC/Polyethylene	
Freeze Point °F	-	25	-15

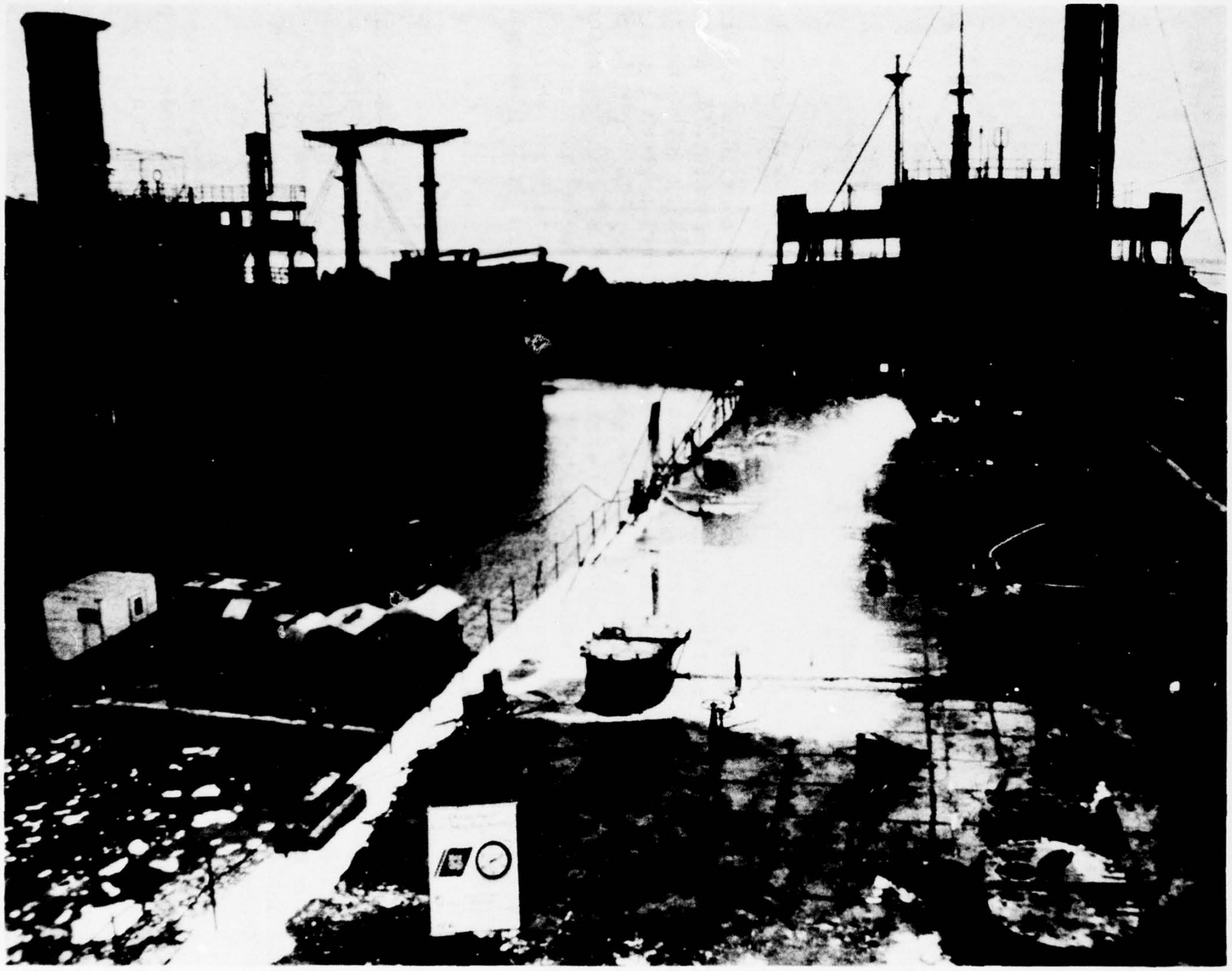


FIGURE 2

RANGE AND PATTERN GRID ON THE A. E. WATTS

3.1.1 Nozzles

The mechanical foam nozzle MFN (Stock No. 4210-225-6225) currently used was evaluated to provide a base line for comparison. The evaluative tests for foam quality, quantity, pattern and range were conducted as described above. The following 1-1/2" nozzles were evaluated to determine the optimum combination:

NOZZLE	ABBREVIATION	REASON
Navy All Purpose	NAP	Used on CG Cutters
Elkhart SFL @ 60 GPM Setting	SFL	Approved by Navy
Akron Style 1715M @ 60 GPM Setting	1751M	Similar to SFL
Akron Style 4315M with 60 GPM Conversion	4315M	Less Expensive 1715
Santa Rosa C-4 with 60 GPM Conversion	C-4	180° Fog - Single Combination
Task Force Tip HTFT-V	HTFH-V	Automatic Flow Adjustment

The last five nozzles are commercially available, constant-flow variable stream nozzles which will be referred to as water fog nozzles in the remainder of this report. They were chosen by asking each manufacturer which nozzle he recommended for the Coast Guard application given the pressure and flow range shown in Figure 1 and the fact that the nozzle would be tested with AFFF. Akron provided both of its nozzles with a simple modification to the standard style. The modification consisted of replacing the baffle plate with one of similar dimensions which had a set of eight impinging holes to increase aeration. This modification was indicated by an "M" following the style number.

3.1.2 In-Line Proportioner

The proportioning rate was measured as a function of inlet pressure at 80, 100, and 125 PSIG. It was determined by two different methods. One method was based on measuring the flow of water into the proportioner and the flow of foam into the proportioner, and calculating the rate. (See Column 8 of Table 2.) The second method employed the "Refractometric Method of Analysis of Concentration of AFFF Solutions."[3,4,5]

The LP-6CG proportioner was used unmodified for all tests involving either 6 percent AFFF or 6 percent protein foam. In order to properly proportion 3 percent AFFF, a simple modification was made. It consisted an adaptor with female 1/2 NPT on the inlet and male 1/2 NPT on the outlet and an internal orifice of 0.120-inch diameter. This adaptor was inserted between the ball check valve and the proportioner (Figure 3). The experimental setup for this portion of the testing is depicted in Figure 4. The pressure drop across the proportioner and the pressure drop downstream of the proportioner were also determined.

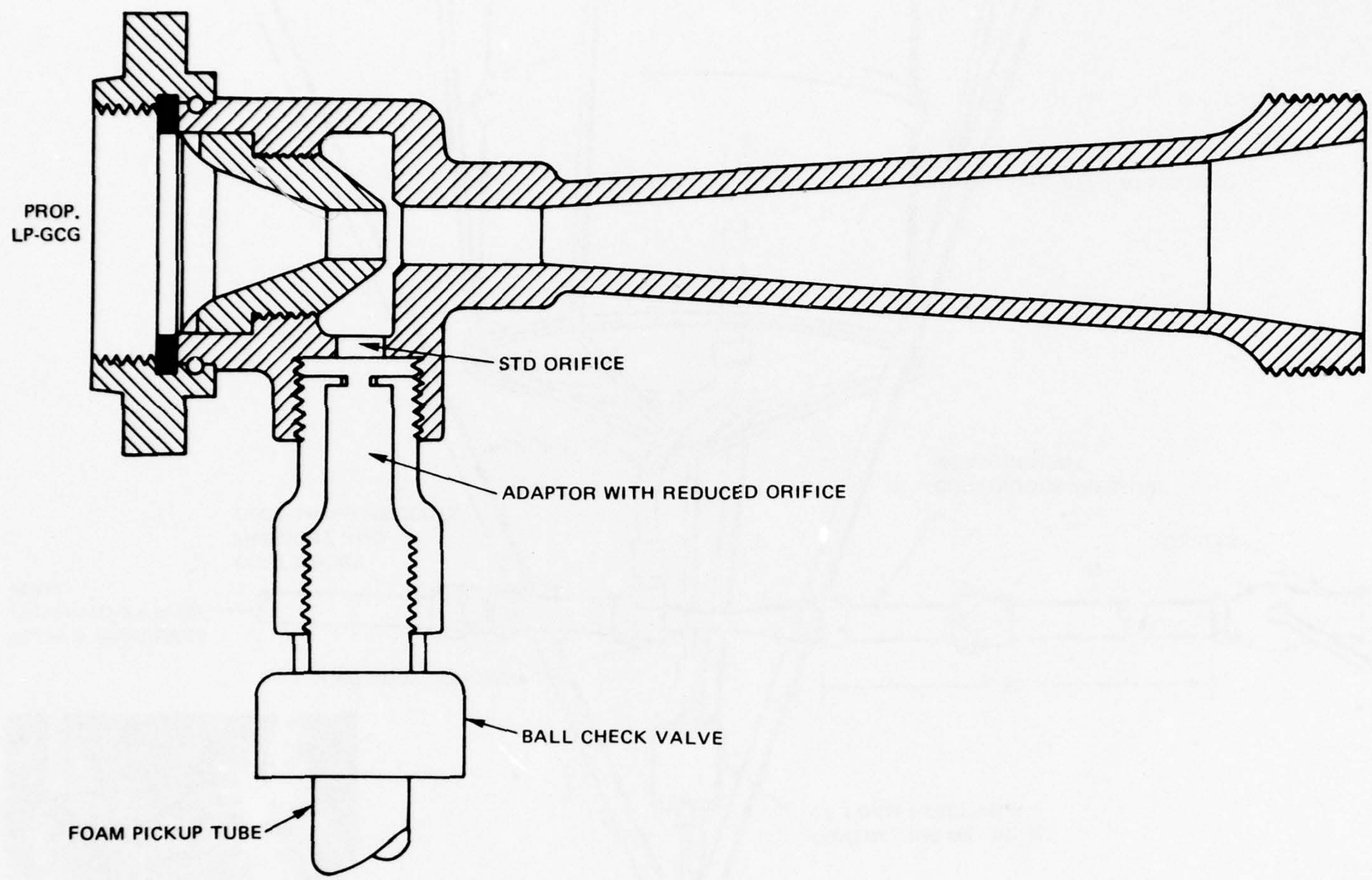


FIGURE 3

LP-6 CG PROPORTIONER AND 3 PERCENT ADAPTER: SECTIONAL VIEW

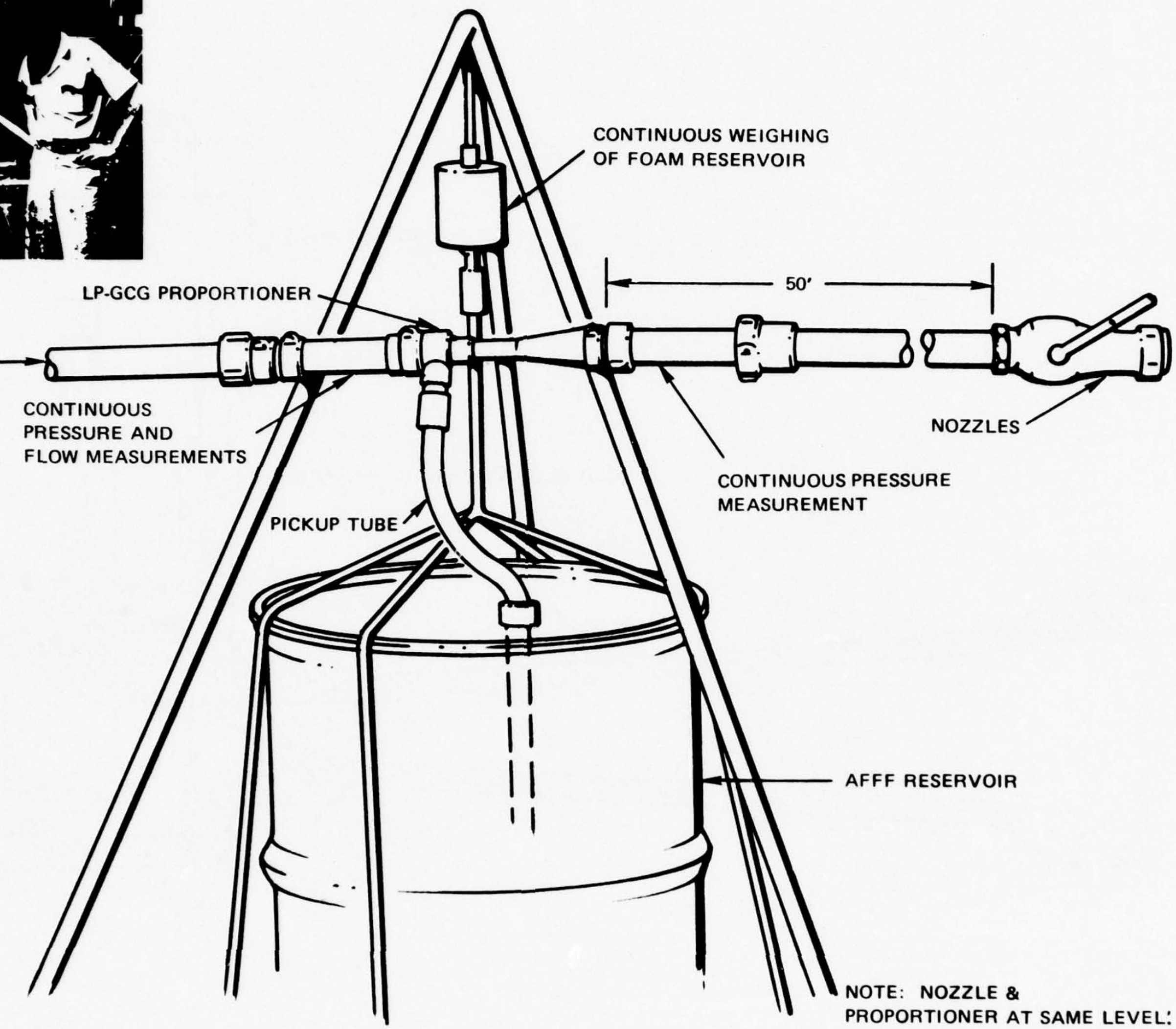


FIGURE 4

INSTRUMENTATION AND **SETUP** FOR PROPORTIONING DURING ALL TESTS

3.1.3 System Evaluation

The proportioner/nozzle combinations were tested as a system. The tests screened out the ineffective systems and thus highlight the optimum proportioner/nozzle combinations. The criteria by which the systems were judged included: foam quality, quantity, pattern and range. Foam quality was determined by measuring the foam expansion ratio and the foam drainage time according to procedures outlined in NFPA 412, Sections A-230 and A-240 respectively. Foam pattern and range were evaluated according to NFPA 412, Section A-300, modified to be used with motion picture documentation of the results. Since foam thickness is not a necessary requirement of a successful AFFF blanket, it was not measured in these tests. The optimum proportioner/nozzle combinations were tested with the nozzle at the same height as the proportioner and with 50 feet of hose between them. During the pattern and range tests the nozzles were held in a fixture which maintained a 30° angle with the deck. The tests were conducted at 80, 100, and 125 PSIG pressure.

A set of tests were conducted to determine the maximum pressure loss between proportioner and nozzle which will still allow foam to be educted into the system. This loss can be due to either head losses or frictional losses in the hoses. To accomplish these tests, a nozzle was connected to the end of 50 feet of hose which was in turn connected to the proportioner and instrumented as shown in Figure 4. The ball valve of the nozzle was then moved from the fully open position to that partially closed position at which the proportioner ceased to educt. The unrestricted flow and downstream pressure and the eductor stall flow and pressure were measured. The stall pressure was then rechecked by completely closing the ball valve and opening it to the point where the proportioner began to educt and recording the flow and pressure.

3.2 Fire Fighting Effectiveness of Combinations

The optimum nozzle proportioner combinations chosen from the previous tests were evaluated for their efficiency in extinguishing full-scale fires. An open deck fire was chosen for these tests. The advantages of this kind of test are that it is economical to conduct, similar to a flight deck fire, and a much more reproducible and severe fire than a machinery space fire. JP-5 was used as the test fuel throughout.

3.2.1 Extinguishment Tests

The open-deck fire extinguishment tests were performed on the after tank deck of the T/V A. E. WATTS. The fuel for the fire was contained by a rectangular array of steel combings measuring 22 by 30 feet and providing a test area of 660 sq. ft. A plan view of the test area is shown in Figure 5. In order to provide a level surface for the fuel, the pens were flooded with water. The fuel was then floated on this water to depths which would permit burning for at least 1 minute longer than the anticipated pre-burn plus extinguishment time. The fires were ignited on the port side of the pen and a pre-burn was measured from the time of full involvement of the test pen to the time when extinguishment was begun. Twenty-five tests were conducted with a one minute pre-burn, and two tests were conducted with a 7-1/2 minute pre-burn.

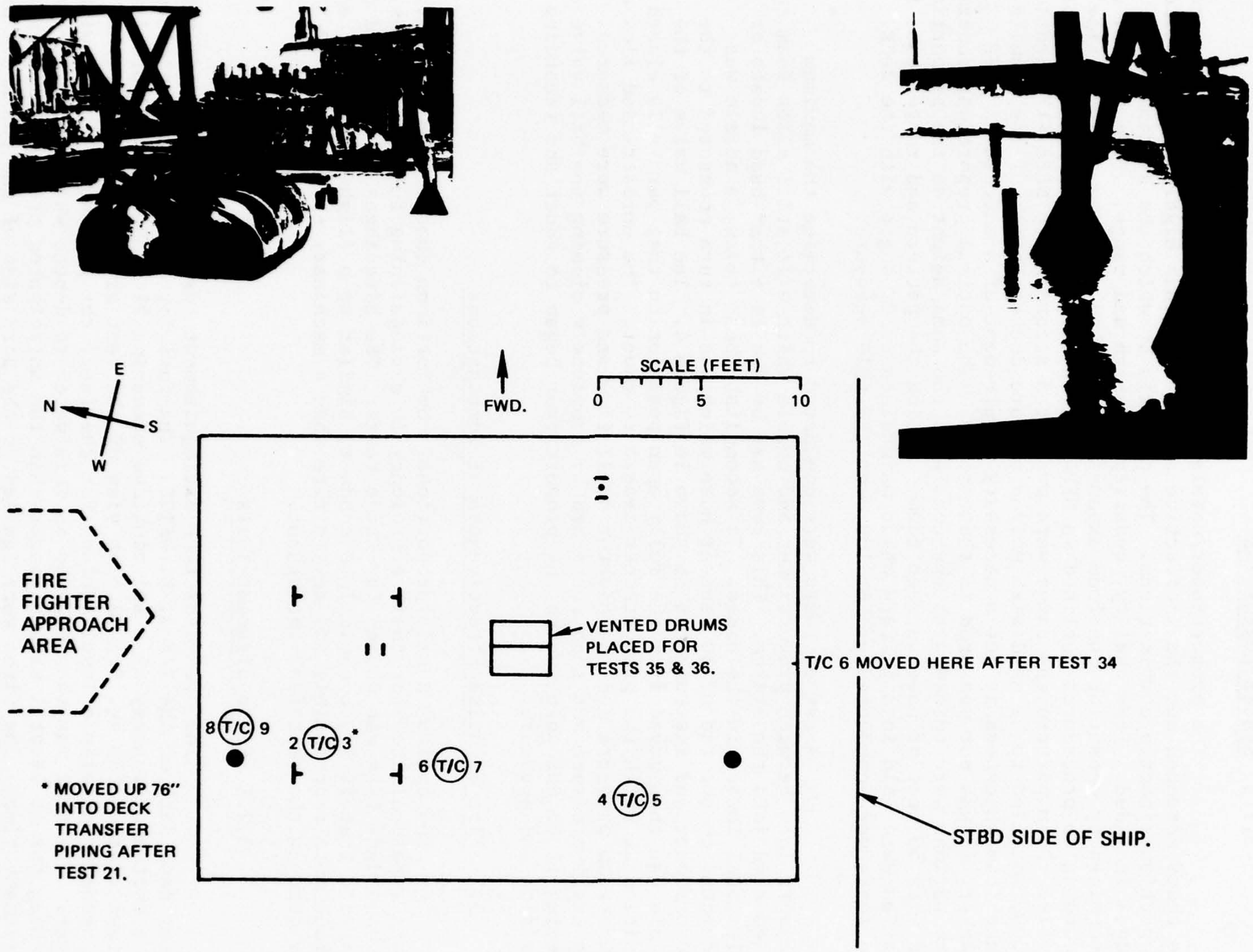


FIGURE 5

PLAN VIEW OF FIRE TEST PEN (660 SQ FT) SHOWING OBSTRUCTIONS AND THERMOCOUPLE T/C LOCATIONS

All extinguishment tests were performed with the nominal system pressure of 100 PSIG. The proportioner was suspended at approximately the same height which the nozzle would be held during extinguishment tests. The fires were fought with firemen's turn-out gear and the approach on the fire was always made from the port side of the test pen. The fire was initially attacked with the nozzle on straight-stream for some tests and on the 30° fog setting for other tests. The 30° fog setting was used to approximate the discharge of the mechanical foam nozzle and also to provide a check on the protection that fog gives a firefighter during extinguishment.

The foam proportioning system was instrumented for the extinguishment tests in the same manner that it was for the evaluative tests. (See Figure 4.) The water flow upstream of the proportioner and the foam flow into the proportioner was used to calculate the foam application rate for each test according to the formula:

$$\text{Application Rate} = \frac{\text{Flow of Foam Solution}}{\text{Area Applied}} = \frac{\left(\begin{array}{c}\text{Flow Upstream}\\ \text{of Proportioner}\end{array}\right) + \left(\begin{array}{c}\text{Flow of Foam}\\ \text{Concentrate}\end{array}\right)}{\text{Area of Test Pen}}$$

Expansion and drainage characteristics were also measured for each test.

The principal data from the extinguishment tests, however, is the control and extinguishment time measurements. Time to control the fire was taken as the time from the beginning of foam applications to the time at which the fire had been 90 percent extinguished. This time corresponds to the point where the fire was subjectively determined to be of no further threat to the vessel or firefighter. It was measured as the average of observations made by 3 or 4 people. Extinguishment time was taken as the time from the beginning of foam application to the time when all fire in the test pen was extinguished. There were obstructions in the test pen during the entire test series as indicated on Figure 5. Additionally, two vented 55-gallon drums were placed on their sides in the center of the test pen for Tests 35 and 36 to further evaluate the foam's capability to seal around obstructions. The junction of chromel-alumel thermocouples were secured to the front and back at the top of two-inch diameter steel pipes. These pipes were placed vertically in the test pen such that the thermocouples were approximately six inches off the fuel surface (see Figure 5). Thermocouples 2 and 3 were moved into the transfer piping above the test pen after Test 21, and Thermocouple 6 was moved to the center top of the starboard combing of the test pen after Test 34. The output of these thermocouples was measured continuously and recorded digitally in the instrumentation van.

3.2.2 Burnback Tests

Burnback testing was conducted for thirteen proportioner/nozzle combinations which successfullly extinguished the previous test fires. The test followed the general guidelines specified in NFPA 412, Section A-620, and in MILSPEC MIL-F-25385, Section 4.7.8.4.3. The first burnback test was conducted with a re-ignitiion fire source produced by inserting a 12-inch diameter stove pipe into the foam blanket, removing the foam, and re-igniting the fuel surface in this area. The remaining burnback tests employed a 23-inch diameter cylinder to produce the burnback fire. This was chosen as a

more severe test so that adequate differentiation could be obtained between foam blankets. One problem often referred to in considering the effectiveness of AFFF is its poor securing or burnback resistance. This problem may paradoxically be due to its rapid extinguishing capabilities. The more rapidly a fire is extinguished, the less foam solution covers the fire; thus, burnback may occur more rapidly through this minimal layer of foam. To evaluate this, 11 of the tests were extinguished with foam being continuously applied for a total of 3 minutes. In 2 tests, the foam application time was reduced to 2 minutes in order to evaluate the effects of the reduced foam blanket. The delay time between the end of fire extinguishment and exposure of the re-ignition source to the foam blanket was maintained approximately constant at 10 minutes for all of the burnback tests. The pre-burn of the re-ignition source was also held constant at 1 minutes for all tests. The time required for the fire to burnback through the foam was recorded as a function of the area of burnback.

4.0 RESULTS AND DISCUSSION

4.1 Evaluative Tests of Proportioner/Nozzle Combinations

Thirteen tests were conducted to determine the principal characteristics of the various nozzles when used in conjunction with the LP-6CG in-line proportioner. Summary of the data for these tests is presented in Table 2. The first test provides the baseline data for the mechanical foam nozzle and 6 percent protein foam to be used for comparison with the water fog nozzles. The next seven tests compare the various nozzles when used with 6 percent AFFF and the last five tests provide the data for comparison with 3 percent AFFF. The HTFT-V nozzle has been eliminated from the discussion of the results because of its failure to permit flow at system pressures of 80 and 100 PSIG. The data for pressure, flow, proportioning rate, expansion ratio and drainage time for the fire tests (see Table 3) were used to expand the data base for the discussion of the evaluative tests.

4.1.1 Pressure Effects

The principal pressure effect on the proportioner/nozzle system is observed as a pressure drop between the upstream and downstream sides of the proportioner. This drop is created by the increased frictional losses in the proportioner and is a function of the flow of the system. For the water fog and mechanical foam nozzles, all of which were designed for flows of 60 GPM, the pressure loss increases with inlet pressure as shown in Figure 6. If 100 PSIG is supplied to the inlet of the proportioner, there is only 60 PSIG at the exit from the proportioner for downstream use. The pressure drop for the Navy All Purpose nozzle which was designed for a flow of approximately 95 GPM is much more severe with a loss of approximately 80 PSIG at 100 PSIG inlet pressure.

When the proportioner is used with 3 percent AFFF, the pressure drop is more severe than when it is used with 6 percent AFFF. This is true for all nozzles (see Figure 6) and can be observed by comparing the straight lines which were fit to both sets of the data by the least squares method. Thus when a water fog nozzle is used in the system proportioning 3 percent AFFF, the usable downstream pressure is approximately 56 PSIG for an inlet pressure of 100 PSIG instead of the 62 PSIG available when 6 percent AFFF is used.

TABLE 2

SUMMARY OF EVALUATIVE TEST DATA

TEST NUMBER	NOZZLE	FOAM TYPE	PRESSURE AT PROPORTIONER		WATER FLOW	FOAM CONCENTRATE USAGE	PROPORTIONING RATE		EXPANSION RATIO	25% DRAINAGE TIME	MAXIMUM RANGE	WIND	
			UPSTREAM	DOWNSTREAM			CALCULATION FROM FLOWS	MEASURED WITH REFRACTOMETER				SPEED	DIRECTION
			PSIG ±2	PSIG ±2	GPM ±1	GAL/MIN ±0.05	%	%		MIN	FT ±2	MPH	°TRUE
1	MFN	6% Protein	86	43	26	2.10	7.5	8.3				1.5	262
			90	53		1.98		6.5				to	to
			100	58		1.80		7.4				4.5	316
			112	69		1.98		6.0					
			127	76		1.84		5.6					
			142	82	36	1.50	4.0	3.4					
2	MFN	6% AFFF	82	53	41	2.38	5.5	7.7	8.8	3.2	44	2.5	250
			100	64	44	2.98	6.3	8.0	8.8	4.3	47	5.0	to
			125	78	47	2.84	5.7	7.2	11.5	1.9	50	3.5	316
3	SFL		77	49	44	2.98	6.3	10.2	4.9	1.5	57	4.0	248
			99	58	47	3.14	6.3	7.0	5.4	1.4	61	4.5	to
			124	69	52	3.08	5.9	8.6	5.1	1.5	63	5.0	306
4	1715M		77	50	41	3.24	7.3	8.6	6.1	1.5	43	4.5	270
			96	61	46	3.07	6.3	8.6	6.0	2.1	51	4.0	to
			125	74	49	3.09	5.9	7.0	6.3	2.0	57	3.8	330
5	C-4		77	54	31	2.11	6.4	5.0	4.0	0.8	51	4.5	150
			97	67	38	2.46	6.1	9.7	4.6	1.1	53	3.5	to
			124	86	43	3.01	6.5	6.3	5.4	1.4	37	3.0	310
6	HTFT-V		80	70	0	0	0	–	–	–	–		250
			100	84	0	0	0	–	–	–	–		to
			122	87	42	1.67	3.8	3.6	3.1	0.7	–	5.5	310
7	NAP		78	18	36	3.30	8.4	8.6	2.0	0	42	5.0	250
			99	22	39	3.09	7.3	7.9	2.5	0	44	4.5	to
			123	26	42	3.33	7.3	7.0	1.8	0	46	4.5	310
8	4315M	6% AFFF	77	52	34	2.77	7.5	7.0	5.1	1.9	41	4.5	250
			100	67	38	2.82	6.9	7.0	5.8	1.7	53	4.5	to
			123	81	43	3.01	6.5	7.0	5.7	1.7	59	3.5	310
9	MFN	3% AFFF	79	50	29	0.99	3.3	3.1	7.3	1.2	38	1.5	010
			103	60	33	1.11	3.3	2.8	9.8	2.6	44	2.0	to
			125	70	37	0.99	2.6	2.2	10.5	2.1	46	3.0	090
10	SFL		81	43	32	0.99	3.0	2.8	4.8	1.6	44	2.5	310
			99	50	35	1.17	3.2	2.8	6.2	1.5	47	2.0	to
			124	61	39	1.06	2.6	2.6	5.5	1.4	50	2.5	020
11	1715M		77	44	29	1.17	3.9	3.1	5.8	1.4	51		130
			100	55	32	1.25	3.8	2.8	6.4	2.0	53	4.0	to
			125	67	38	1.17	3.0	2.2	6.9	1.8	55		160
12	4315M		78	52	27	0.99	3.5	3.1	7.0	1.8	38	3.0	150
			103	62	31	1.03	3.2	2.8	6.4	2.0	50	3.0	to
			125	73	36	1.06	2.9	2.5	5.8	1.3	52	2.0	210
13	NAP	3% AFFF	80	16	27	1.03	3.7	3.1	2.2	0.3	27	2.0	130
			103	19	32	0.99	3.0	2.0	2.2	0.1	29	1.0	to
			125	22	35	1.03	2.9	2.0	2.2	0.1	33	3.0	200

NOTE: ALL NOZZLES ON STRAIGHT STREAM PATTERNS

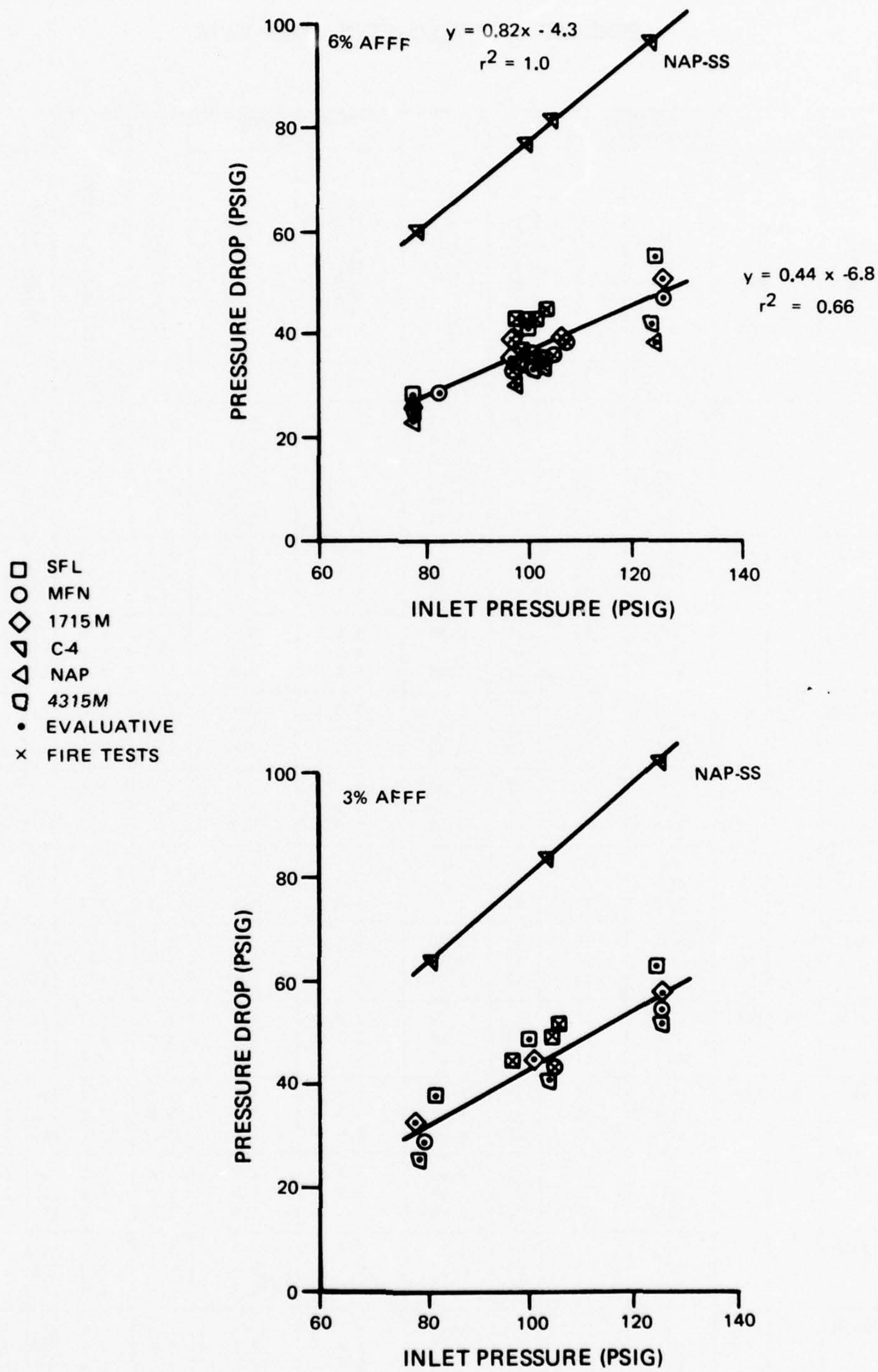


FIGURE 6

PRESSURE DROP ACROSS CG-6 LP PROPORTIONER
AS A FUNCTION OF INLET PRESSURE

The 4315M nozzle was used in the tests conducted to determine the maximum pressure loss between proportioner and nozzle which would still allow the eduction of foam. This nozzle was chosen because its pressure and flow characteristics were very similar to but slightly lower than the MFN, SFL, and 1715M nozzles. Thus, the results obtained would be conservative relative to these nozzles. The empirical results of the tests were manipulated to show what combinations of inlet pressure to the proportioner (P_I) in PSIG, number of 50-foot hose lengths (N), and nozzle height above the proportioner (h) in feet would just cause the proportioner to stall out. These manipulations follow, by definition:

a. $P_N = P_o - P_F - P_h$

where P_N is nozzle pressure, P_o is the pressure on the outlet side of the proportioner, P_F is the pressure loss due to friction and P_h is the pressure loss due to heat. From manufacturers data (Figure 7, A):

b. $\text{Log } P_N = 2 \text{ Log } Q - 1.61$

where Q is the flow through the nozzle. From empirical data at the education stall point (Figure 7, B):

c. $P_o = 0.9\ P_I - 9.5$

from hose manufacturers data (Figure 7, C):

d. $P_F = N(0.13\ Q - 1.9)$

from empirical data at the educator stall point (Figure 7, D):

e. $Q = 0.17\ P_I + 23$

and from the standard head loss equation:

f. $P_h = 0.43h$

combining these equations to eliminate Q and solving for h:

g. $h = .0017\ P_I^2 + 1.6\ P_I - .05\ NP_I - 2.4N - 53$

Equation (g) thus describes the relationship between h, P_I, and N. It is only valid for $70 \geq P_I \geq 130$ since linear approximations were made in this range and for the system proportioning 6 percent AFFF with the foam reservoir between 2 and 3 feet below the proportioner. The tests were conducted with a foam temperature of approximately 50°F. If the temperature were lower, the viscosity of the AFFF would increase and the relationship would have to be reduced. When values are substituted into equation (g), the following results are obtained.

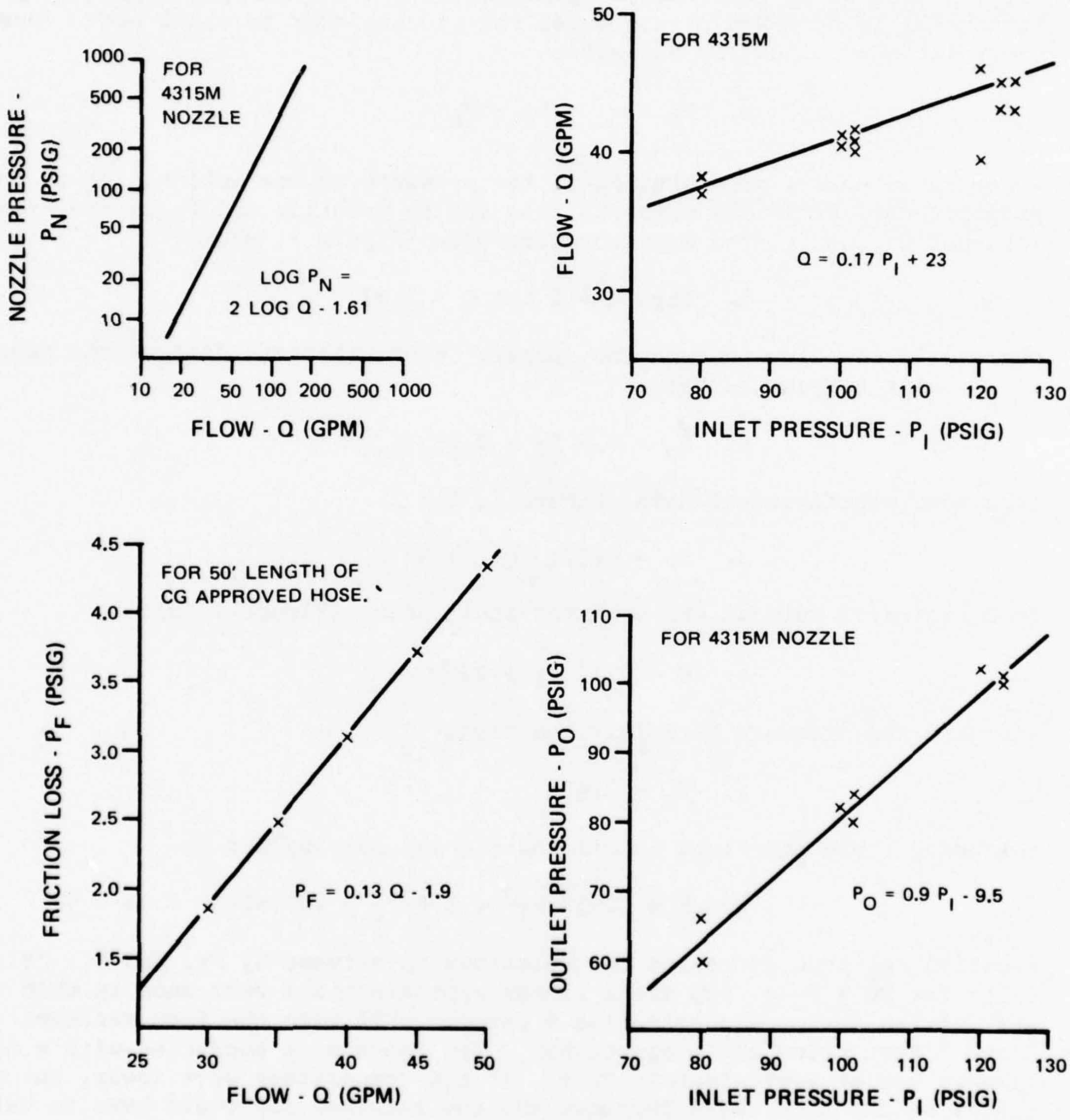


FIGURE 7

EMPIRICAL DATA FOR DETERMINING PRESSURE, HEIGHT, AND NUMBER OF HOSE LENGTHS AT THE PROPORTIONER STALL POINT

P_I	N	h
80	1	60
100	1	86
125	1	116
80	2	54
100	2	79
125	2	108
80	3	48
100	3	72
125	3	100
80	4	42
100	4	65
125	4	92

A review of this table shows that within practical limits of pressure, height and number of hose sections the CG-6LP proportioner is capable of foam production.

4.1.2 Flow, Proportioning Rate and Foam Usage

Flow through the proportioner/nozzle system is shown as a function of the pressure at the upstream side of the proportioner for all nozzles in Figure 8. If we compare the flow for each nozzle at 100 PSIG inlet pressure, the following ranking is obtained:

RANKING	NOZZLE	FLOW (GPM)
1	SFL	48
2	1715	46
3	MFN	44
4	NPA	39
5	4315M	38
6	C-4	38

The nozzles would maintain the same relative position if ranked at other pressures since all of the flow/pressure relationships were essentially parallel. Thus using flow as the ranking criteria, one would have to consider the first three nozzles as essentially equivalent while the last three nozzles produce lower flow rates. The graph of flow versus pressure of the mechanical foam nozzle indicates the advantage of 6 percent AFFF over 6 percent protein foam. The advantage is that flow through the system is approximately 50 percent higher when using the 6 percent AFFF than when using protein foam at the same inlet pressure. Thus, when there is a constraint on the maximum system pressure such as observed on our cutters, more firefighting foam can be made available when using a 6 percent AFFF.

Figure 8 also shows that the system flow for 6 percent AFFF is from 20 to 35 percent greater than for 3 percent AFFF for all of the nozzles evaluated. The drop in flow for 6 percent protein foam over 6 percent AFFF is due to the higher viscosity of this foam. The drop in flow for 3 percent AFFF

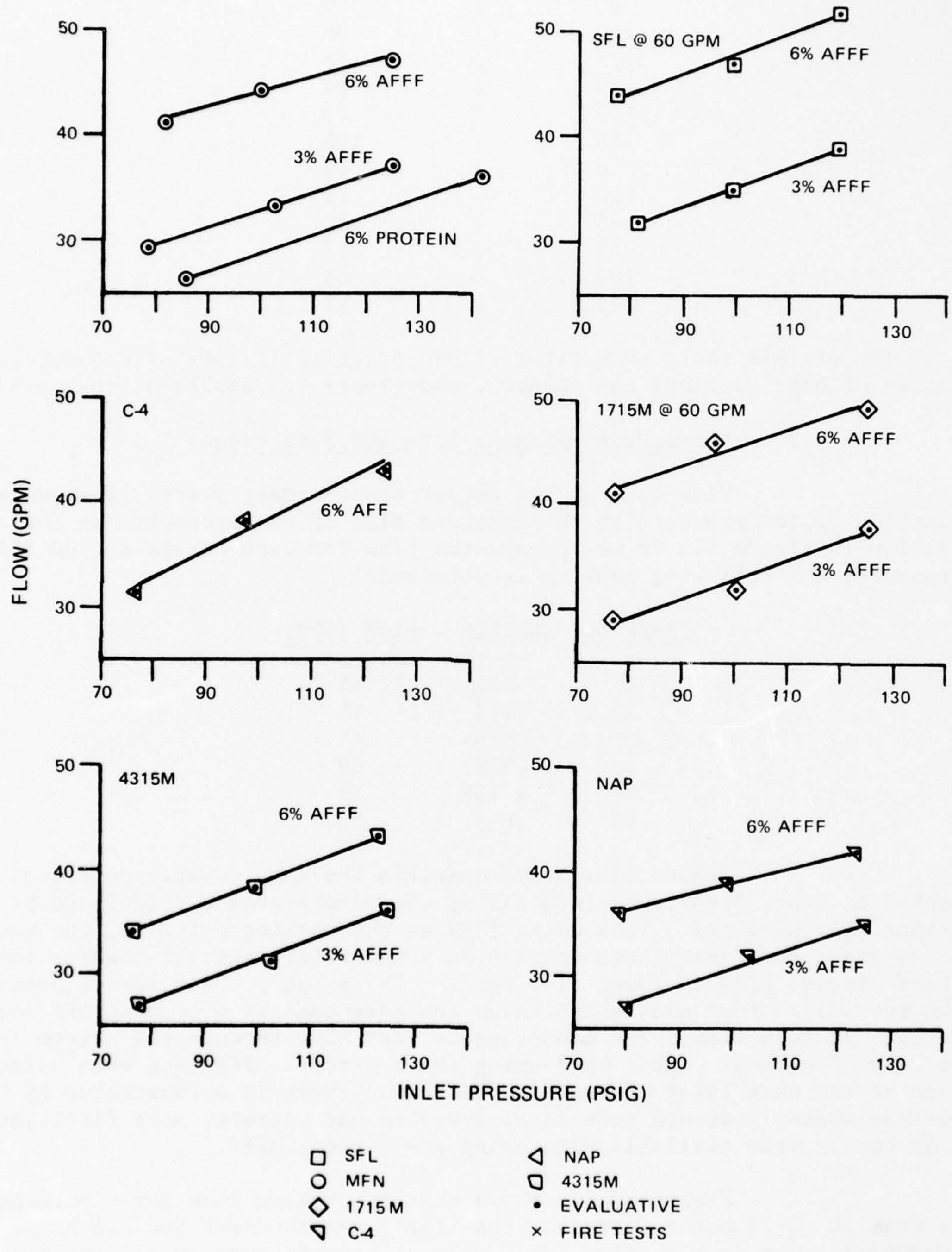


FIGURE 8

FLOW THROUGH NOZZLE/PROPORTIONER SYSTEM AS A FUNCTION OF INLET PRESSURE

is due to the smaller orifice required in the proportioner. It does show, however, that while 3 percent AFFF may save a 50 percent storage weight in volume, it will also reduce the flow of foam to the firefighter when the system is constrained by an in-line proportioner.

The results of the two methods for determining the proportioning rate, as described in Section 3.1.2, are shown in columns 8 and 9 of Table 2. A comparison of these columns will show that the proportioning rate, as calculated from the flow of foam concentrate and water into the proportioner, is generally somewhat less than that measured by the refractometric method. One reason for this discrepancy is oil and other contaminents which are picked up by the fire pump at the intake suction. The measurement of water flow at the proportioner is generally insensitive to these impurities and thus the proportioning rate calculated from the flows directly reflects the percentage of foam introduced into the stream as if the stream were 100 percent water. The refractometric method requires a sample taken subsequent to the discharge from the nozzle. This sample can include the impurities from the bay as well as the foam concentrate induced by the proportioner and thus the refractive index would be increased by the proportion of the impurities present. The subsequent proportioning rate calculated would reflect this increase. For this reason the proportioning rate as calculated from the water and foam flows was used for presentation in Figure 9.

All of the water fog nozzles produced similar proportioning rates when combined with the CG-6LP proportioner as seen in this figure. The rates range between 5 and 9 percent foam concentrate in solution. When the evaluative test data is compared to the fire test data, it is noted that the latter produced proportioning rates somewhat higher (7-9 percent) while the former produced proportioning rates between 5 and 7 percent. While much of the fire test data is for nozzles used in the 30 degree fog position, as indicated on the figure, there are still several data points for straight stream patterns which fall on the high side. The Navy All Purpose nozzle when used on the straight stream pattern produces a proportioning rate which is somewhat higher than for the water fog nozzles. This is to be expected because of the higher pressure drop across the proportioner.

The proportioning rates produced with the CG-6LP proportioner as modified for 3 percent AFFF fall much closer to the nominal proportioning rate of 3 percent. Their range is from 2.6 to 4 percent and the pressure drop seems to have little significant effect over the range explored.

As the proportioning rate increases, the foam usage for any period of time increases even through the extinguishment or control time for fire suppression may not improve. Therefore, from a conservation of foam concentrate point of view, it is incumbent on the designer to bring the proportioning rate of the system into alignment with the concentrate being used. This will permit firefighting for the greatest length of time. This seems to have been adequately done for the modification producing 3 percent AFFF. A similar modification for the proportioner for 6 percent AFFF may be able bring the proportioning rate into align.

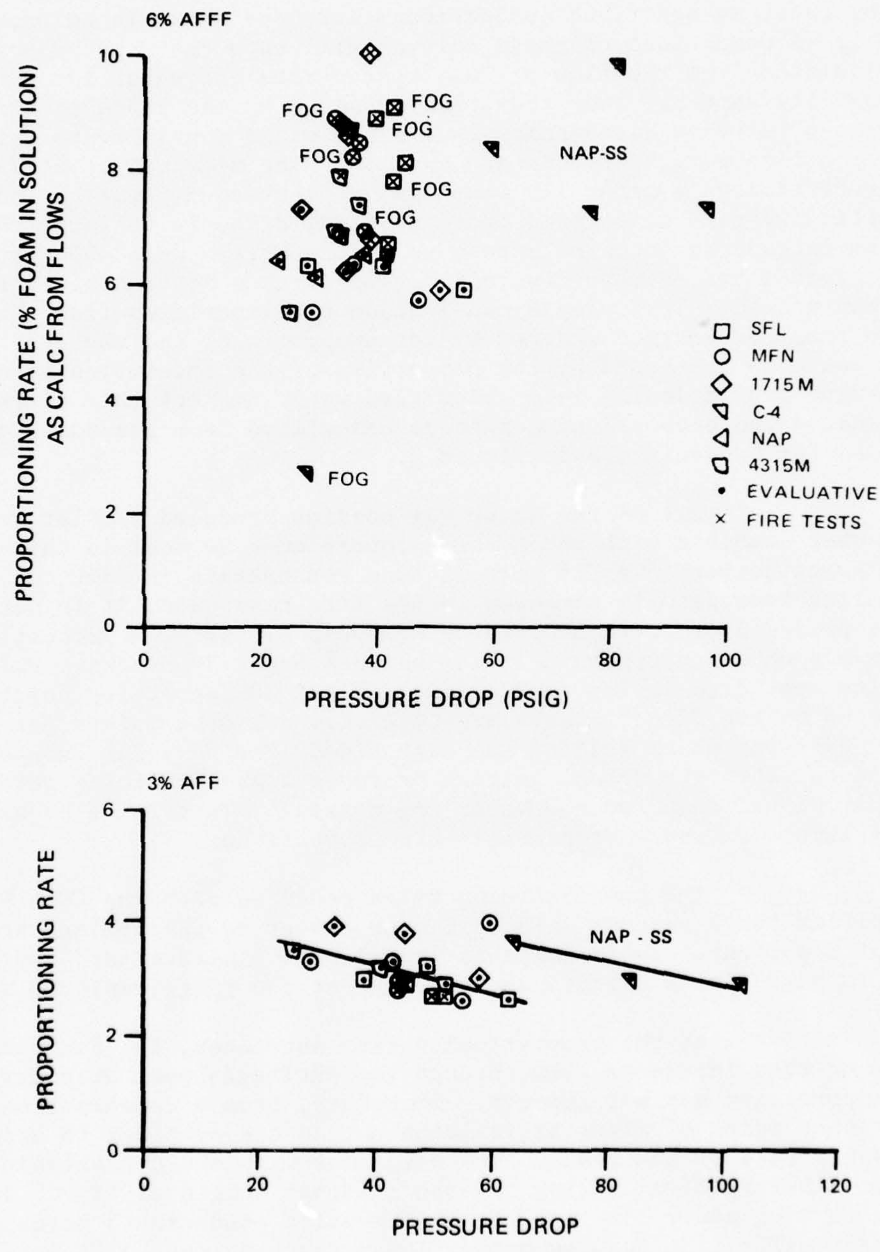


FIGURE 9

PROPORTIONING RATE AS A FUNCTION OF PRESSURE DROP ACROSS PROPORTIONER

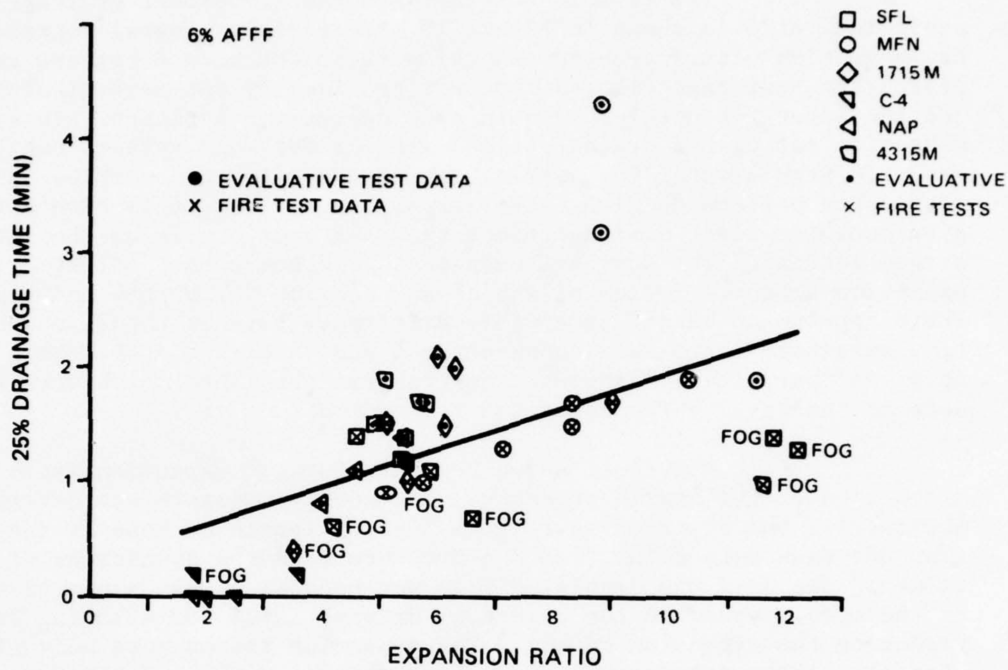
4.1.3 Expansion and Drainage Characteristics

The relationship between the 25 percent drainage time and the expansion ratio is shown in Figure 10. There is a general increase in the drainage time with increased expansion ratio for both 6 percent and 3 percent AFFF. The best expansion ratios were provided by the mechanical foam nozzle and the water fog nozzles when in a 30 degree fog position. In general, the expansion ratios and drainage times are low for foam systems but this is to be expected from a water fog nozzle. While the water fog nozzles on the 30 degree fog pattern do give better expansion ratios, it is also noted that they give somewhat lower drainage times than the same nozzle on the straight stream setting. The Navy All Purpose nozzle gives the poorest drainage and expansion characteristics of any of the nozzles for both 6 and 3 percent AFFF. There appears to be no discernible difference between the 25 percent drainage time/expansion ratio relationship for 6 and 3 percent AFFF. This can be observed most clearly by comparing the straight lines which were fit to both sets of the data by the least squares method.

Figure 11 shows the data for the expansion ratio plotted as a function of the nozzle pressure. The nozzle pressure was determined by subtracting the friction loss for a 50-foot length of hose at the recorded flow for each data point from the pressure measured downstream of the proportioner. The data was displayed this way because it was expected that pressure at the nozzle would be the principal driving force for aerating foam and thus producing the expansion ratios. The expansion ratios were only plotted for straight stream patterns because the combination of wind and foam board placement caused too much variation in the expansion ratio data when the nozzles were on the 30° fog pattern. It shows that there is no clear relationship for the data as a whole but there is a general increase in expansion ratio with nozzle pressure if the nozzles are considered individually. It is clear from this graph that the Navy All Purpose nozzle produces an expansion ratio which is inferior to all of the other nozzles evaluated. This is true for both 6 and 3 percent AFFF. The mechanical foam nozzle, on the other hand, produces expansion ratios which are clearly superior for both foam concentrates. The water fog nozzles as a group produce expansion ratios between 4 and 7. Within this group, the C-4 gives the poorest expansion ratios. Since it was the only water fog nozzle which did not have impinging holes, this indicates that these holes are effective in increasing the expansion ratio. Of the remaining water fog nozzles, there is not clear superiority of one over the other.

4.1.4 Range and Pattern

The maximum range for each of the nozzles is plotted as a function of the system pressure as measured on the upstream side of the proportioner in Figure 12. The maximum range was taken as a visual average over 1 minute's time of the furthest point from the nozzle of the straight stream pattern. The patterns for all nozzles were similar, ragged elipses with major diameter between 12 and 15 feet and minor diameter between 5 and 7 feet. It is seen that the SFL nozzle gives slightly longer range than the other water fog nozzles when used with 6 percent AFFF. The Navy All Purpose nozzle gives the poorest range of any of the nozzles evaluated. The mechanical foam nozzle also gives shorter maximum ranges than the other water fog nozzles. The ranges of the mechanical foam nozzle decreases even further as it is bent in use. For example, at 100 PSIG system pressure, its range is approximately 45



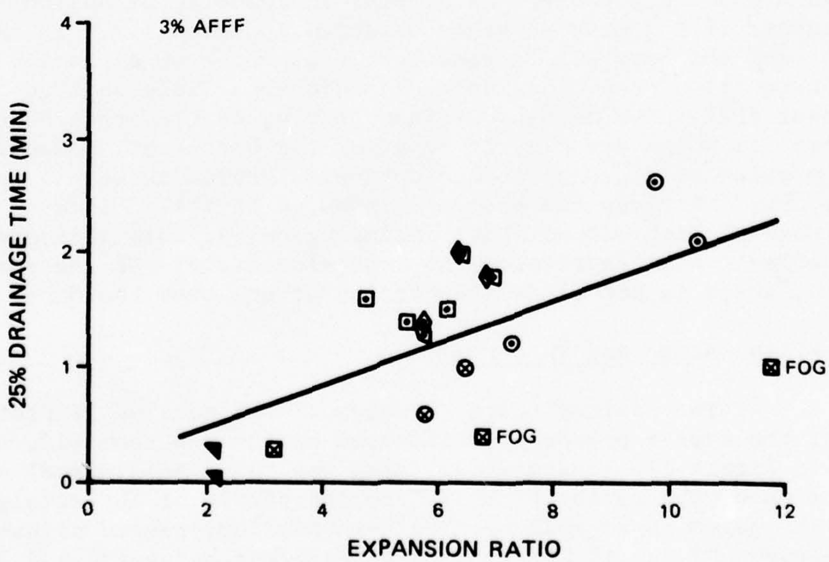


FIGURE 10

TWENTY-FIVE PERCENT DRAINAGE TIME AS A FUNCTION OF EXPANSION RATIO

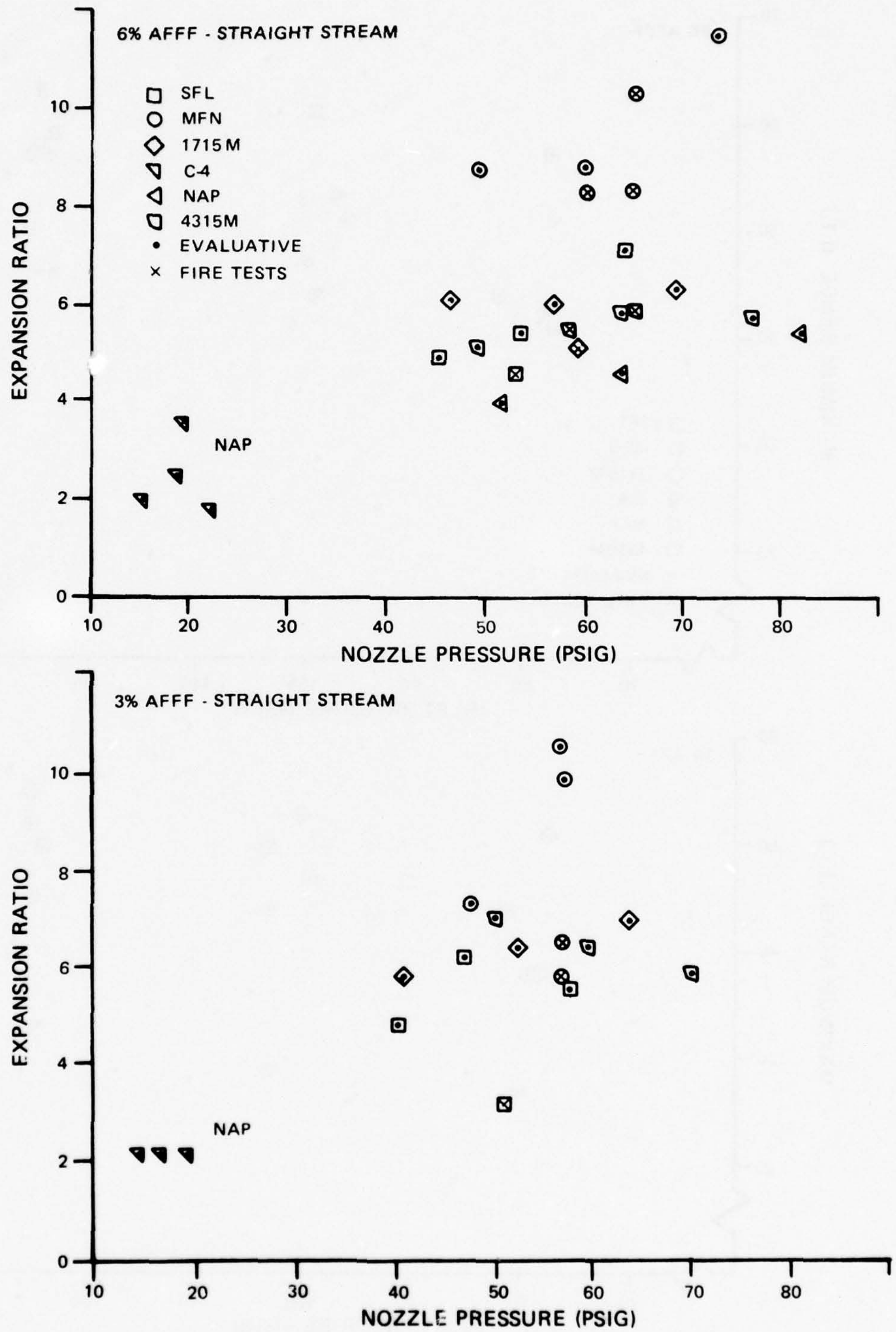


FIGURE 11

EXPANSION RATIO AS A FUNCTION OF NOZZLE PRESSURE

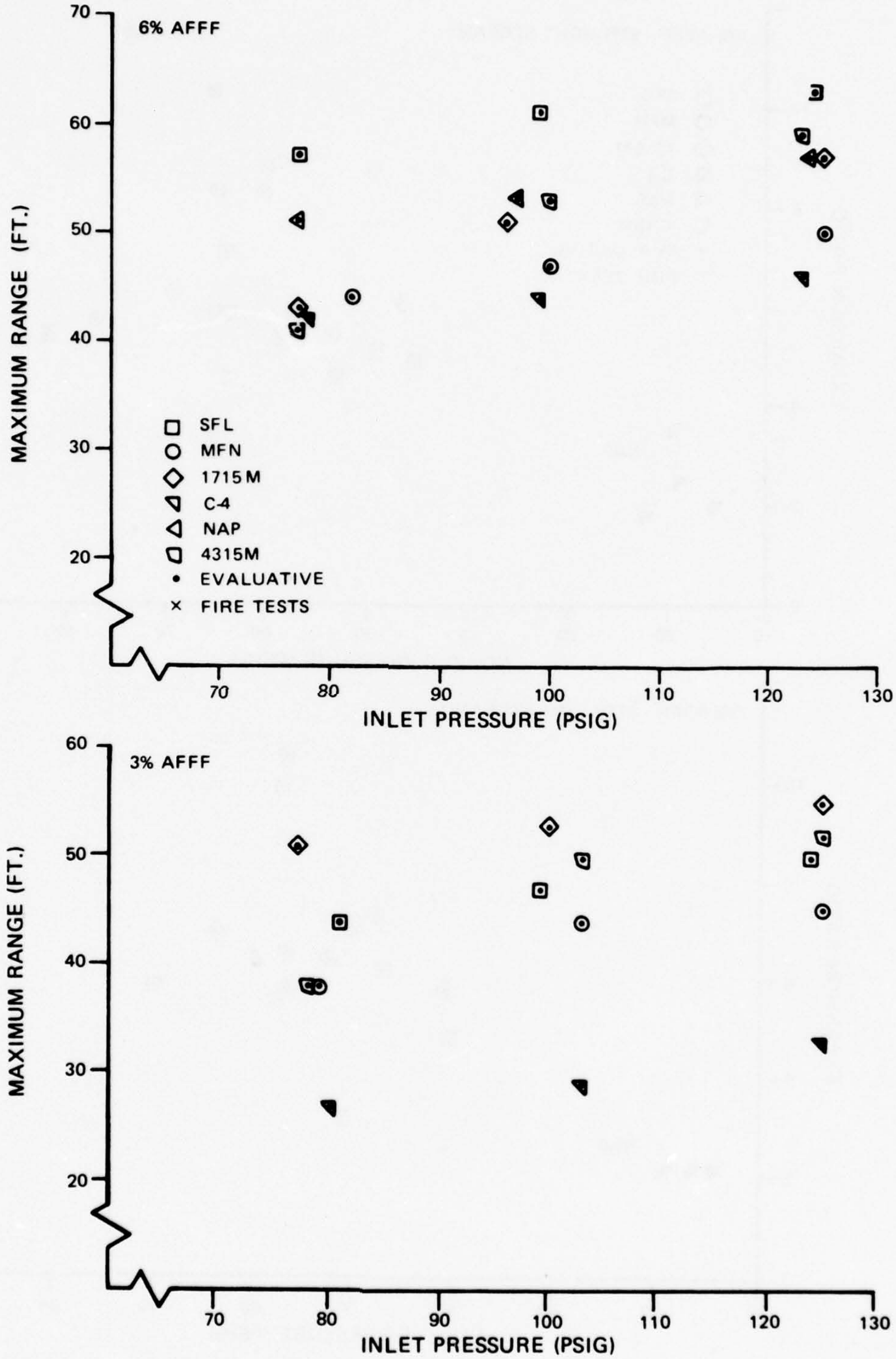


FIGURE 12

MAXIMUM RANGE AS A FUNCTION OF INLET PRESSURE

feet but when the nozzle is bent to approximately a 90 degree angle, the range decreases to 18 feet. This is to be expected because the bending of the nozzle will increase the frictional loss in it and therefore reduce the driving force that produces range. When used with 3 percent AFFF, the 1715M nozzles produced slightly better range than the SFL.

The range of a general purpose nozzle for shipboard use is especially important in combatting deck fires. Initially, it can provide the firefighter a capability of attacking the fire while remaining at a reasonable distance from it. As the fire is knocked down, it permits clean-up of remaining fire areas without having the firefighter traverse the previously burned fuel. When the general purpose nozzle is used in the engine room, however, the straight stream pattern can be a liability. The principal problem is that the stream will find its way to any electrical wiring or panels which are still live, thus producing the hazard of electrical shock to the firefighter.

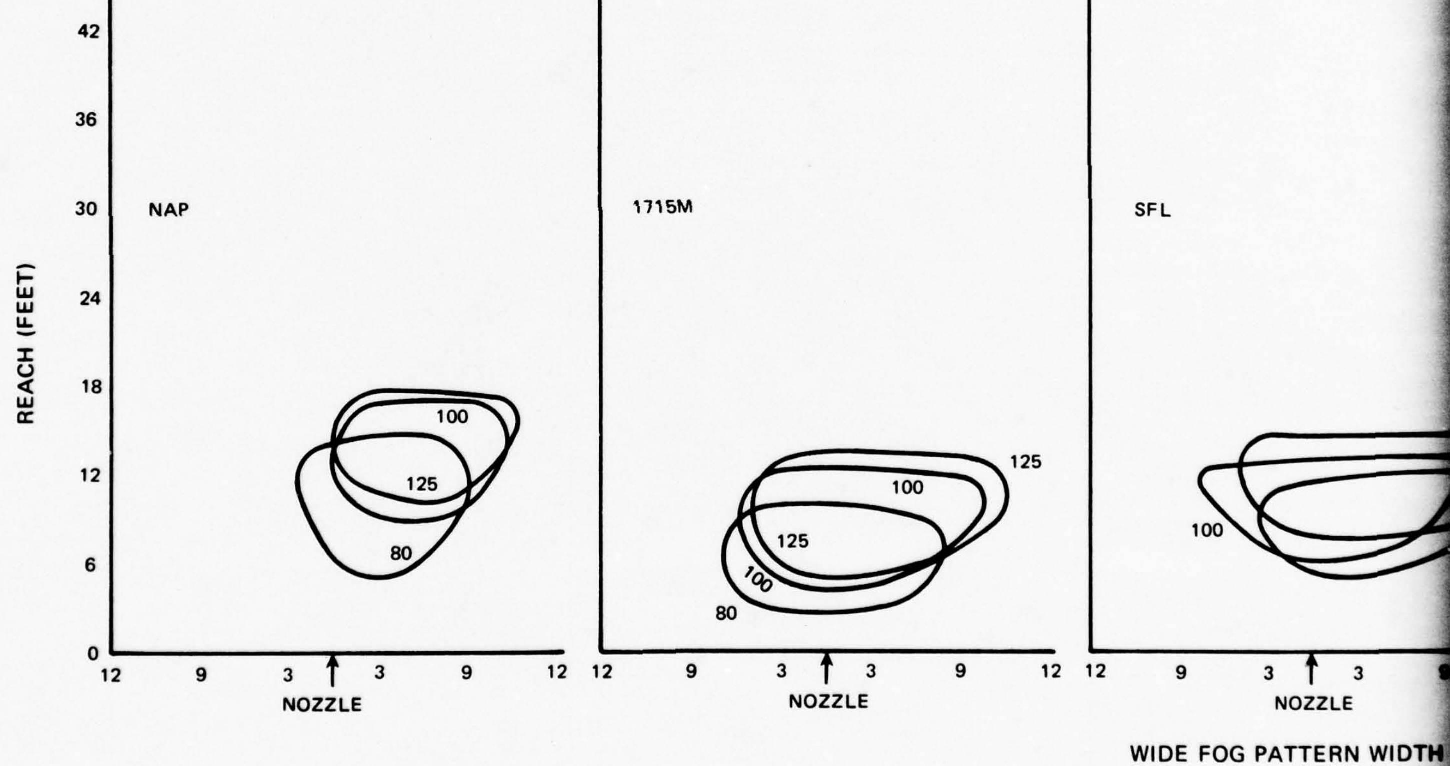
The characteristics of the wide fog patterns are displayed in Figure 13. The Navy All Purpose nozzle gives the poorest wide fog pattern. Its pattern more nearly resembles a 30° narrow fog pattern produced by the other water fog nozzles. The 4315M nozzle also gives a fairly narrow fog pattern but with slightly more reach than the other nozzles. The C-4 nozzle gives the widest fog pattern of any nozzle evaluated. It spreads water out in approximately a 180° water curtain and breaks it into a very fine mist which provides a very good heat shield for the nozzle man. The reach of this pattern is very poor, however. The 1715M and the SFL nozzles give very similar fog patterns which have a maximum of approximately 15 feet of reach at 125 PSIG and a width of approximately 15 feet.

The advantages of fog patterns take up where straight streams leave off. The widest fog pattern provides an extremely effective heat-absorbing barrier in front of the nozzle man; however, it has limited capability for knocking down a Class B fire. A 30° fog pattern, on the other hand, provides some protection to the nozzle man as well as a fairly adequate capability for knockdown of Class B fires. The wide fog patterns for the 1715M and SFL nozzles are probably the best for the Coast Guard application because they provide a limited knockdown capability with 18 feet of reach and yet good fire barrier for the nozzle man. The advantage of the water fog nozzles over a mechanical fog nozzle is the capability of having both that protective shield and the range for adequate knockdown and cleanup in one simple control on the nozzle. The disadvantage is that when in close spaces, the nozzle may be inadvertently placed in the straight stream position, thus bringing on the electrical shock hazards previously mentioned.

4.1.5 Six Percent AFFF Compared to Three Percent AFFF

The two AFFF concentrates have the similarities discussed previously. The testing also showed that the expansion ratio and drainage characteristics for the two concentrates were essentially equivalent (see Figure 10). A significant disadvantage of the 3 percent concentrate was highlighted during the testing. It first became apparent when observing the pressure loss across the proportioner. The 3 percent concentrate caused a

NOZZLE	NAP	1715M	SFL
DESCRIPTION OF WIDE FOG PATTERN	NARROW FOG PATTERN	HEAVY PATTERN IN CENTER FINE MIST ON FRINGES.	SERIES OF COARSE SPURS RADIATING FROM NOZZLE AND BREAKING INTO FOG. HEAVY PATTERN IN CENTER



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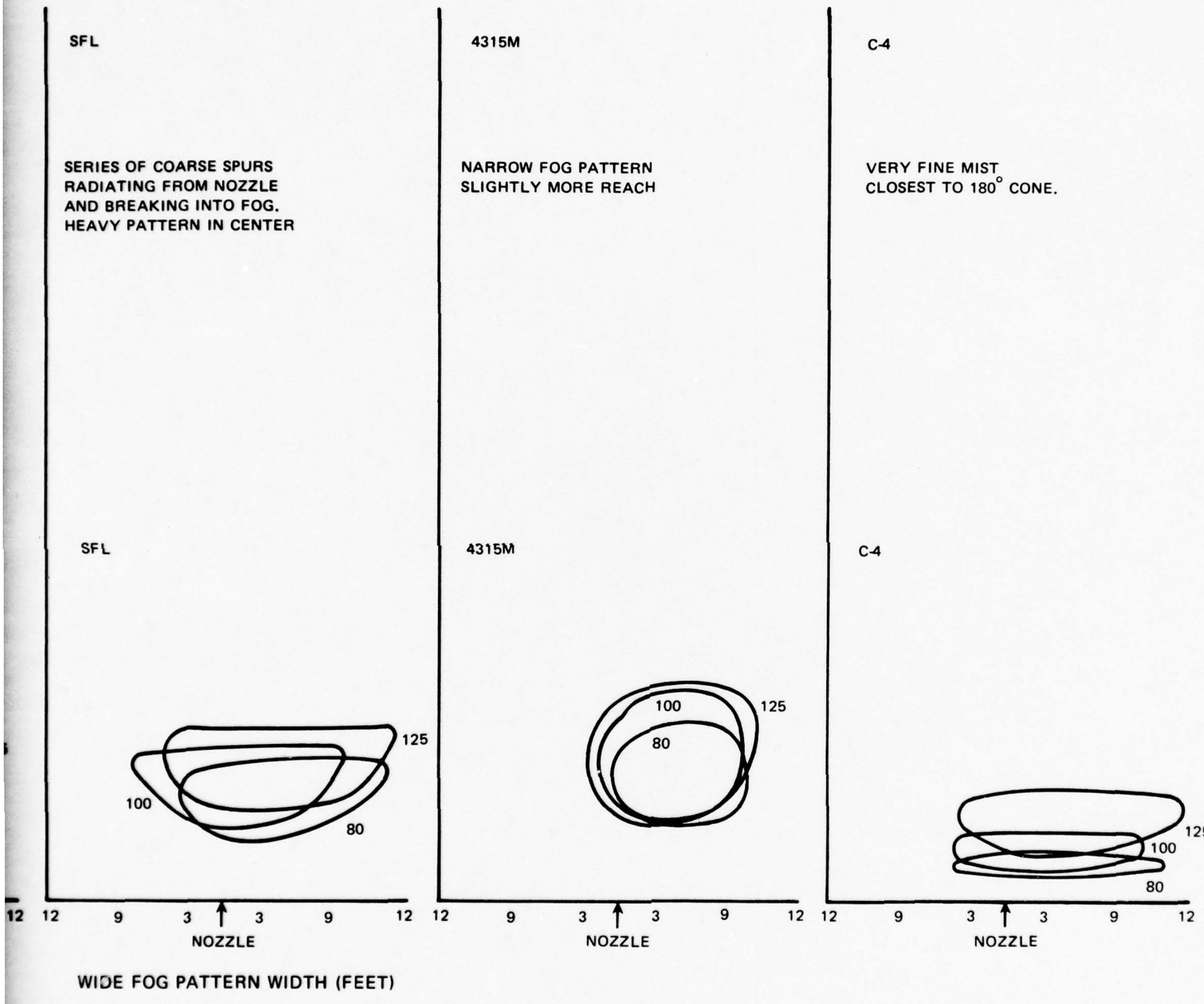

FIGURE 13

CHARACTERISTICS OF WIDE FOG PATTERNS

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much higher loss than the 6 percent concentrate (see Figure 6). This is due to the reduced orifice required in the proportioner in order to properly proportion the foam into the water stream and is a function of the type of proportioner. In-line proportioners, in general, will require this smaller orifice and thus the larger pressure loss that goes with it; however, positive displacement proportioners and other foam proportioning systems would probably not be placed at this disadvantage when using 3 percent AFFF. The disadvantage is also reflected in the fact that the flow for 6 percent AFFF is from 20 to 35 percent greater than for 3 percent AFFF when it is constrained by the CG-6LP proportioner (see Figure 8). The greater pressure drop across the proportioner also leaves less pressure at the nozzle and thus the range for a nozzle using 3 percent AFFF is decreased (see Figure 12).

4.2 Firefighting Effectiveness of Combinations

Twenty-five extinguishment tests were conducted to evaluate the effectiveness of the different nozzles in combination with the CG-6LP proportioner. Twenty of the tests employed 6 percent AFFF while five employed 3 percent AFFF and two employed 6 percent protein foam for comparative data. The summary of the data for these tests is presented in Table 3 and the beginning of extinguishment is shown in Figure 14. Thirteen tests were conducted to evaluate the burnback resistance of the various foams produced; 6 percent AFFF was used in nine of the tests, 3 percent AFFF was used in two tests, and 6 percent protein foam was used in two tests again for comparative data. The principal data for the burnback tests is presented in Table 4. The C-4 nozzle was eliminated from both the extinguishment and burnback tests because of its relatively poor ranking when compared to the other water fog nozzles in the evaluative tests. While the Navy All Purpose nozzle also had a very poor ranking in the evaluative tests, it was nevertheless used during the fire tests because of its inherent advantage of being currently available on Coast Guard cutters.

4.2.1 Control and Extinguishment Results

The data for the fire extinguishment tests is displayed on a plot of application rate versus control time in Figure 15. Control time was chosen over extinguishment time for display because of its more consistent nature. The figure shows that application rates as low as 0.05 gpm/sq. ft. can be used to successfully control fires with hand lines. These results compare favorably with the application rates of 0.04 gpm/sq. ft. reported elsewhere.[7,8] An examination of Figure 15 shows that there are two distinct groupings of the data. It turns out that these groupings are really a separation created by extinguishment technique. The two techniques will be referred to as the methodical and aggressive techniques. The methodical technique can best be described as slow, cautious, and deliberate. The nozzle man initially stood back from the fire until the foam stream had knocked down the fire and then he approached cautiously for final cleanup and extinguishment. It was a defensive technique from beginning to end. In the aggressive technique the nozzle man was constantly on the offensive. He used a rapid advance with wide, fast sweeping motions. In a few cases a heat absorbant water screen was provided for him by a backup hose team. He continuously took the foam to the fire, during knockdown, cleanup and final extinguishment.

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TABLE 3

SUMMARY OF FIRE TEST DATA

			PRESSURE AT PRO-PORTIONER				PROPORTIONING RATE							WIND	
TEST NUMBER	NOZZLE AND PATTERN	FOAM TYPE	UPSTREAM	DOWNSTREAM	WATER FLOW	FOAM CONCENTRATE USAGE	CALCULATION FROM FLOWS	MEASURED WITH REFRACTOMETER	EXPANSION RATIO	25% DRAINAGE TIME	PREBURN TIME	CONTROL TIME	EXTINGUISHMENT TIME	SPEED	DIRECTION
			PSIG ±2	PSIG ±2	PSIG ±2	GAL/MIN ±0.05	%	%		MIN	MIN	SEC	SEC	MPH	°TRUE
17	MFN	6% AFFF	107	69	42	3.13	6.9		10.3	1.9	1	42	135	4.0	170 to 280
18	SFL-F		101	58	38	3.21	7.8		11.8	1.4		57	163	4.0	220 to 250
19	SFL-SS		99	57	44	3.18	6.7		4.6	1.4		36	163	5.5	240 to 270
20	1715M-F		97	62	37	3.49	8.6		3.5	0.4		47	96	3.5	240 to 260
21	1715M-SS		96	57	48	3.49	6.8		5.1	1.5		31	88	3.0	245 to 270
22	4315M-F		102	68	44	3.25	6.9		11.6	1.0		31	60	1.5	240 to 270
23	4315M-SS		98	61	30	2.39	7.4		5.5	1.2		LOST FIRE DUE TO OVERFLOW OF FUEL			
24	4315M-SS		103	68	33	3.13	8.7	7.6	5.9	1.1		30	--	2.0	330 to 020
24A	NAP-SS		104	22	34	3.71	9.8	9.0	3.6	0.2		80	170	4.0	270 to 330
25	NAP-F		104	76	32	0.87	2.7	3.1	1.8	0.2		35	110	4.0	320 to 340
25A	MFN		104	68	37	3.31	8.2	8.0	8.3	1.5		25	63	3.5	320 to 000
26A	SFL-F		97	54	33	3.31	9.1	9.0	6.6	0.7		20	80	3.5	330 to 020
27	1715M-F		106	67	32	3.57	10.0	9.0	5.5	1.0		22	55	4.0	040 to 080
28	4315M-F		98	64	33	2.83	7.9	8.4	4.2	0.6		23	45	2.0	000 to 090
29	MFN		96	63	32	3.13	8.9	9.0	8.3	1.7		23	45	2.0	000 to 070
30	1715M-WF	6% AFFF	97	63	31	2.98	8.8	8.0	9.0	1.7		97	--	2.5	000 to 060
31	MFN	6% Protein	98	64	35	2.84	7.5	8.0	5.7*	1.7*		37	105	3.0	040 to 090
32	MFN	6% Protein	97	61	35	2.87	7.6	8.0	5.8*	1.4*	1	65	130	3.0	050 to 080
33	MFN	6% AFFF	98	63	32	3.05	8.7	9.0	7.1	1.3	7.5	25	95	1.5	260 to 100
34	SFL-F		97	57	34	3.31	8.9	7.6	5.4	1.2	7.5	22	65	3.0	320 to 040
35	MFN		101	66	--	3.21	---	8.6	5.7	1.0	1	23	70	1.0	040 to 070
36	SFL-F	6% AFFF	103	58	37	3.28	8.1	8.0	12.2	1.3		25	55	1.5	050 to 080
37	SFL-F	3% AFFF	96	51	36	1.09	2.9	2.6	11.8	1.0		35	60	0.5	--
38	MFN		104	60	35	1.06	2.9	2.8	6.5	1.0		27	110	1.5	050 to 090
38A	MFN		104	60	37	1.07	2.8	2.2	5.8	0.6		25	60	2.0	050 to 100
39	SFL-SS		104	54	37	1.04	2.7	1.6	3.2	0.3		25	60	1.5	050 to 090
39A	SFL-F	3% AFFF	105	53	38	1.04	2.7	2.2	6.8	0.4	1	22	45	2.0	040 to 080
	(1)								(2)	(2)					

NOTE 1 - F INDICATES NOZZLE SET FOR 30° FOG
SS INDICATES NOZZLE SET FOR STRAIGHT STEAM
WF INDICATES NOZZLE SET FOR WIDE FOG

NOTE 2 - * INDICATES DATA TAKEN WITH AFFF FOAM BOARD

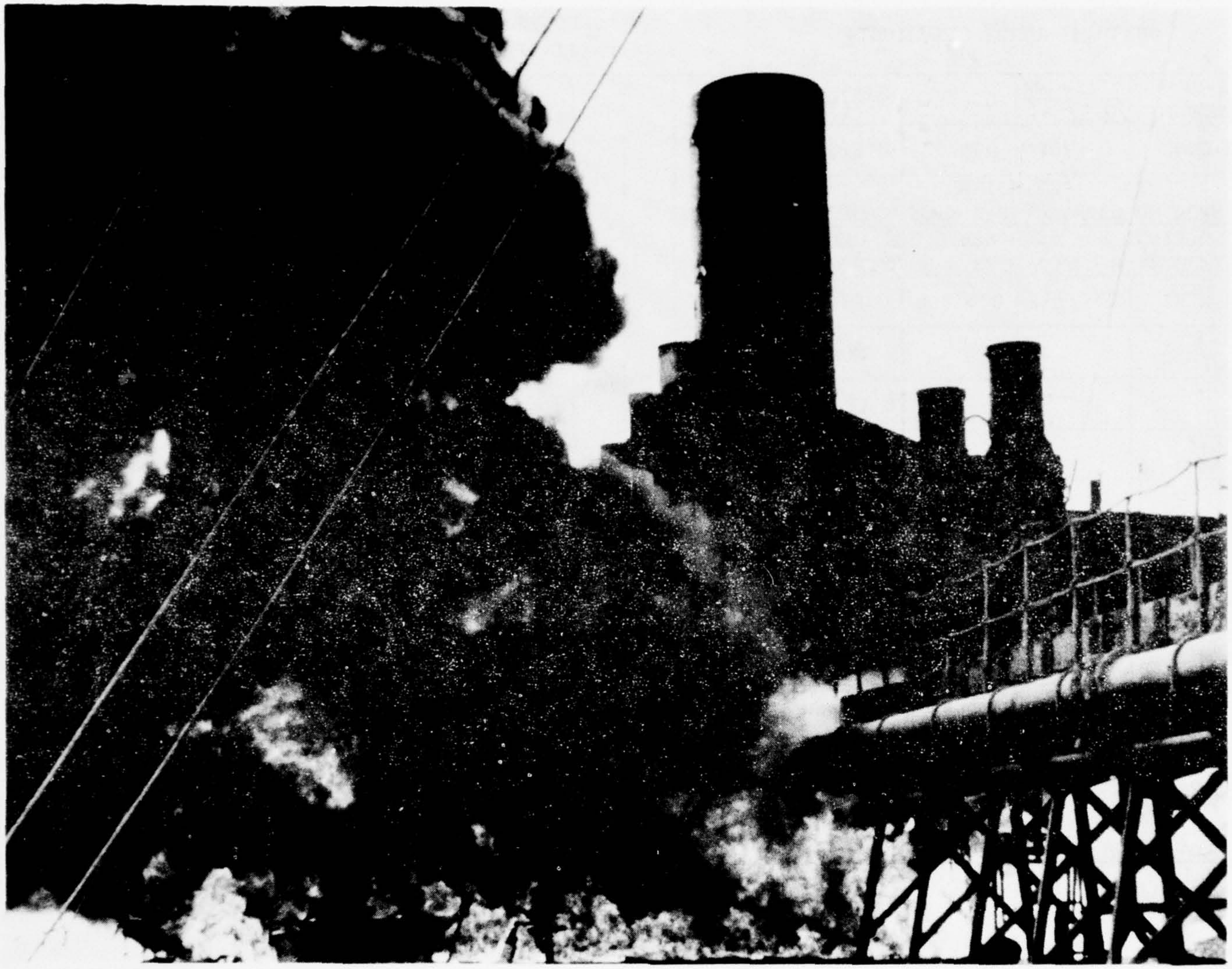


FIGURE 14

INITIAL APPROACH ON 600 SQ FT JP-5 DECK FIRE

TABLE 4

BURNBACK TEST DATA

TEST NO.	NOZZLE & PATTERN	FOAM TYPE	FOAM APPLICATION TIME MIN	DELAY PERIOD MIN ±0.2	BURNBACK FIRE DIAMETER IN	PREBURN TIME MIN	BURNBACK AREA(SQ FT)/TIME (min)				OBSERVATIONS
17	MFN	6% AFFF	3	10	12	1	SMALL BURNBACK SOURCE, EXTINGUISHED IN 0.1 MIN				
20	1715M-F				23		66/1.8	165/2.3	330/3.3	660*/4.3	
21	1715M-SS						2.2/0.2	2.2/3.0	20/5.0		IDEAL BLANKET LOW WIND
22	4315M-F						1.2/0.2	10/5.0			
24	4315M-SS						165/0.8	330/1.1	660*/1.7		
25	NAP-F						330/0.7	660*/1.3			MINIMAL BLANKET BLEW OFF
25-A	MFN		3				165/1.1	660*/1.9			30% UNCOVERED DUE TO WIND
26	FCN		2				330/0.8	660*/1.3			30% UNCOVERED DUE TO WIND
27	1715M-F	6% AFFF	2	10		[2]	1.2/0.2	2.9/3.0	4.4/4.0	8.7/5.0	THIN BLANKET
31	MFN	6% PROTEIN	3	11[1]		[2]	BLANKET ADVANCED ON FIRE - WOULD HAVE EXTINGUISHED EXCEPT FOR PAPER USED FOR IGNITION.				
32	MFN	6% PROTEIN		10			AFTER 4.0 MINUTES FOAM HAD ADVANCED ON BURNBACK FIRE SLIGHTLY.				
37	SFL-F	3% AFFF					1.9/0.2	5.8/3.0	20/4.0	30/5.0	GOOD BLANKET
38	MFN	3% AFFF	3	10	23	1	1.9/0.2	5.0/2.0	15/3.0	165/5.0 660*/7.4	BLANKET NOT AS FROTHY

NOTE[1] - DELAY PERIOD WAS LONGER DUE TO DELAY IN IGNITING FIRE
NOTE[2] - SLOW IGNITION REQUIRED SLIGHTLY LONGER PREBURNS

*INDICATES FULLY INVOLVED

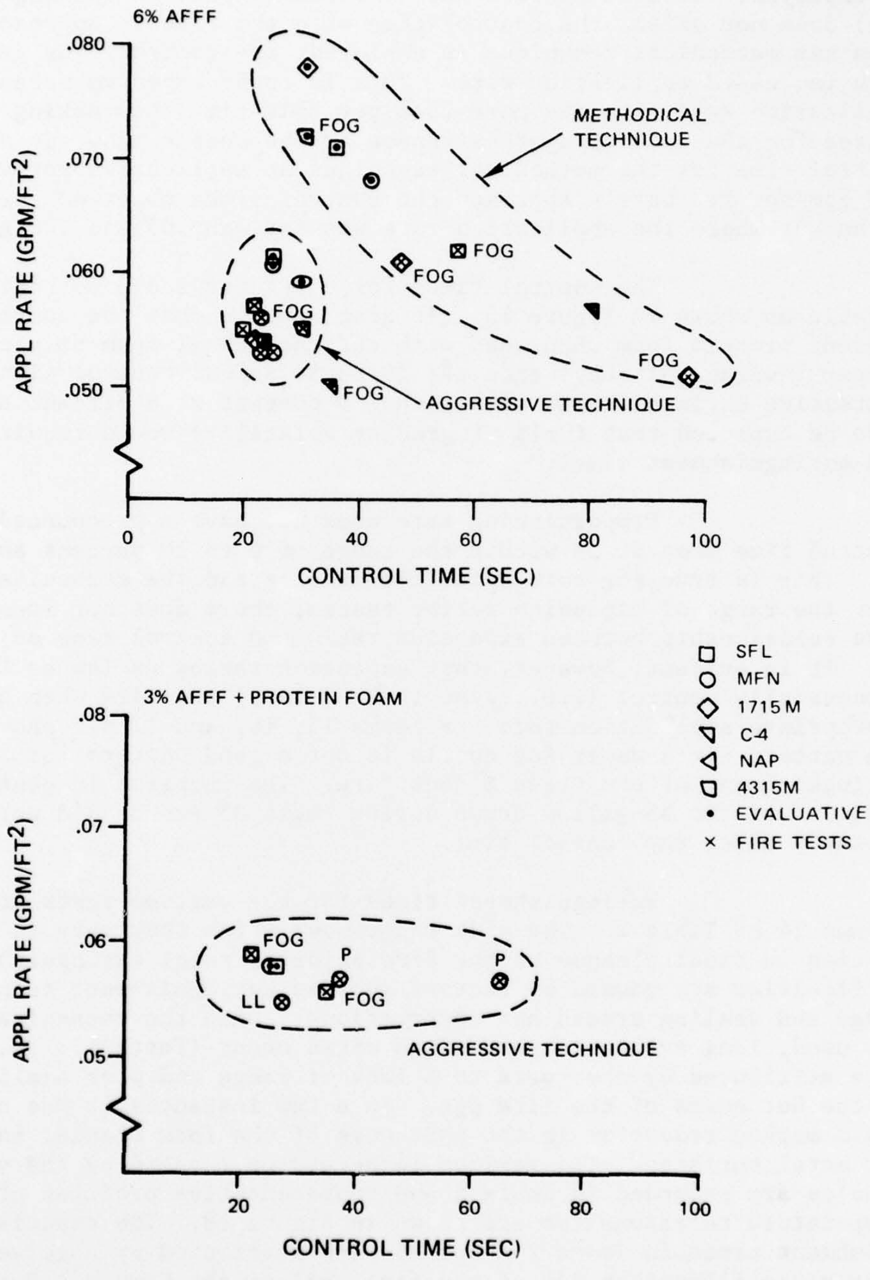


FIGURE 15

APPLICATION RATE AS A FUNCTION OF CONTROL TIME

The aggressive technique produces rapid extinguishment (20 to 30 seconds) while the slower methodical technique can take as long as 100 seconds depending upon application rate. The effectiveness of the various nozzles cannot be differentiated by control time when the aggressive technique is employed. It also appears that the nozzle pattern (straight stream or 30° fog) does not affect the control time when the fire is approached aggressively. When the methodical technique is employed, the control time generally decreases with increased application rate. This is to be expected because the increased application rate provides more foam per unit time thus making up to some degree for the lack of aggressiveness of the nozzle man. In any event, the control time for the methodical technique at application rates between .07 and .08 gpm/sq. ft. barely approach the control times observed for the aggressive technique where the application rate was between .05 and .06 gpm/sq. ft.

The control times for 6 percent and 3 percent AFFF are comparable as shown in Figure 15. It also appears that the control time for 6 percent protein foam when used with the mechanical foam nozzle is somewhat longer (average 51 sec.) than the 20 to 30 second control time observed for aggressive extinguishment with either 3 percent or 6 percent AFFF. It would also be expected that fuels of greater volatility would require longer control and extinguishment times.[9]

Proportioning rate does not have a pronounced effect on the control time when it is within the range of 6 to 10 percent as shown in Figure 16. This is true for both water fog nozzles and the mechanical foam nozzle. Over the range of expansion ratios tested, there does not seem to be a definitive relationship between expansion ratio and control time as shown in Figure 17. It is evident, however, that expansion ratios as low as four can be used to successfully control (i.e., less than 30 sec.) the fire when applied at the appropriate application rate. Figures 15, 16, and 17 all show that the wide fog pattern for a water fog nozzle is not a good pattern for control and extinguishment of the Class B deck fire. The increase in obstructions by the addition of two 55-gallon drums during Tests 35 and 36 did not seem to significantly alter the control time.

Extinguishment times for the various tests are presented in column 14 of Table 2. The wide range over which they vary is caused by difficulties in final cleanup of the fire prior to total extinguishment. These difficulties are caused by factors such as extinguishment technique, nozzle range and sealing around hot obstructions. When the mechanical foam nozzle was used, long extinguishment times often occur (Tests 17, 33, and 38). These were attributed by observers to a lack of range and poor sealing of the AFFF at the hot edges of the fire pen. In a few instances it was noted that there was a marked reduction in the thickness of the foam blanket in the vicinity of hot metal surfaces. The maximum temperatures reached by the various thermocouples are recorded in Table 5 and representative profiles of the time/temperature relationships are shown in Figure 18. The especially long extinguishment times in Tests 24A and 25 were attributed by observers to the very poor range (less than 3/4 of the fire pen) of the Navy All Purpose nozzle. The nozzle man actually had to walk into the fire pen in order to totally extinguish the fire.

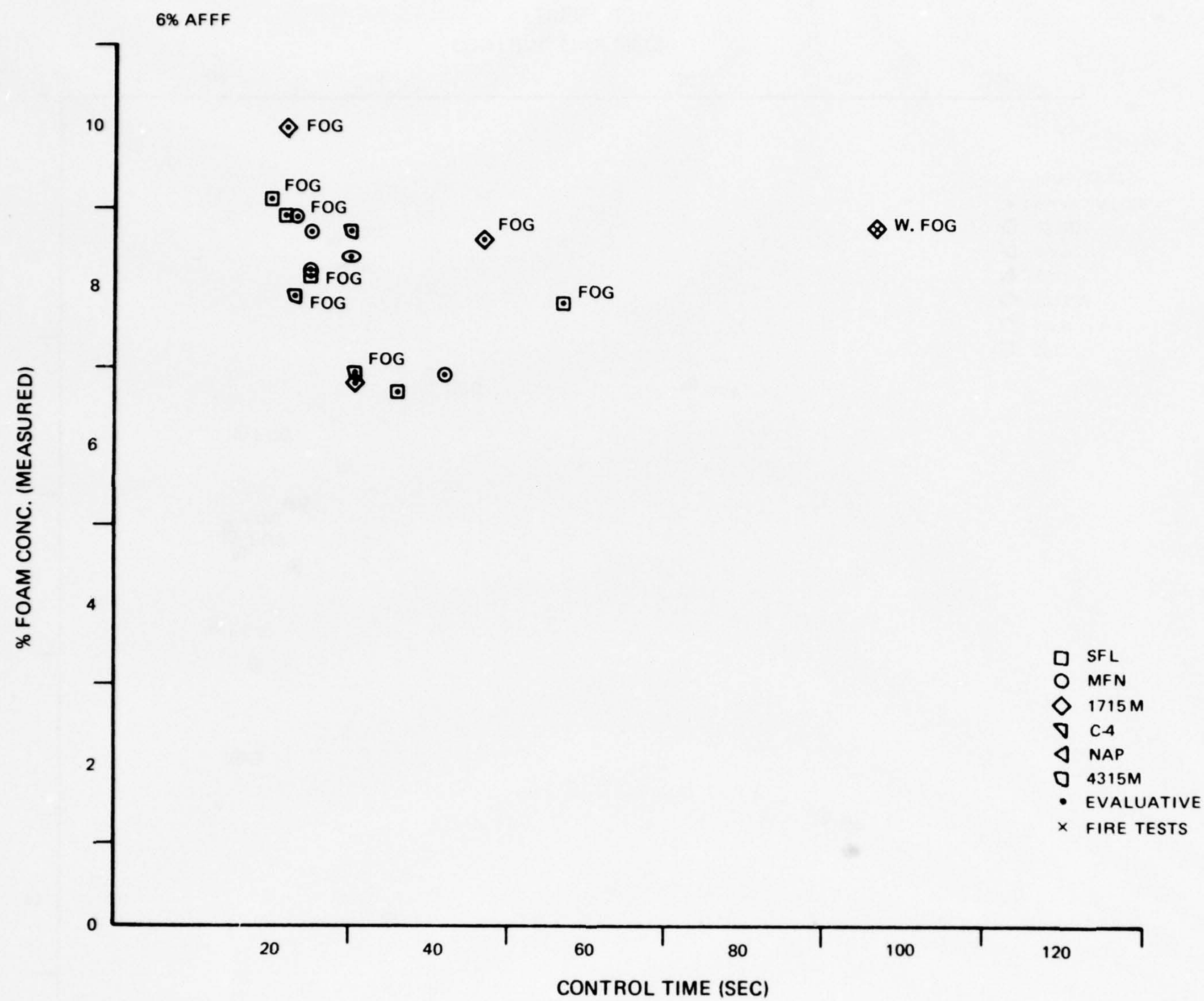


FIGURE 16

PROPORTIONING RATE AS A FUNCTION OF CONTROL TIME

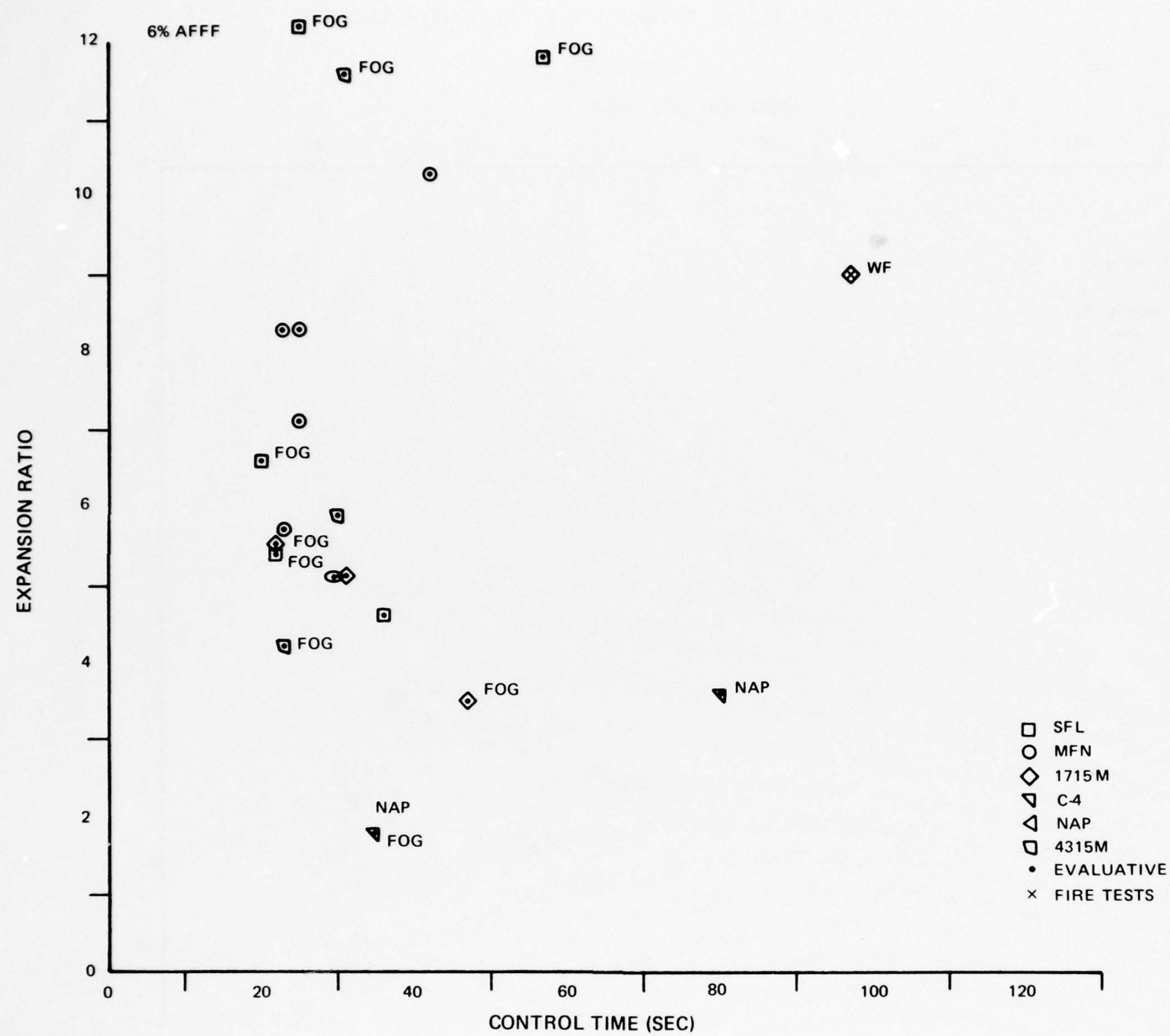


FIGURE 17

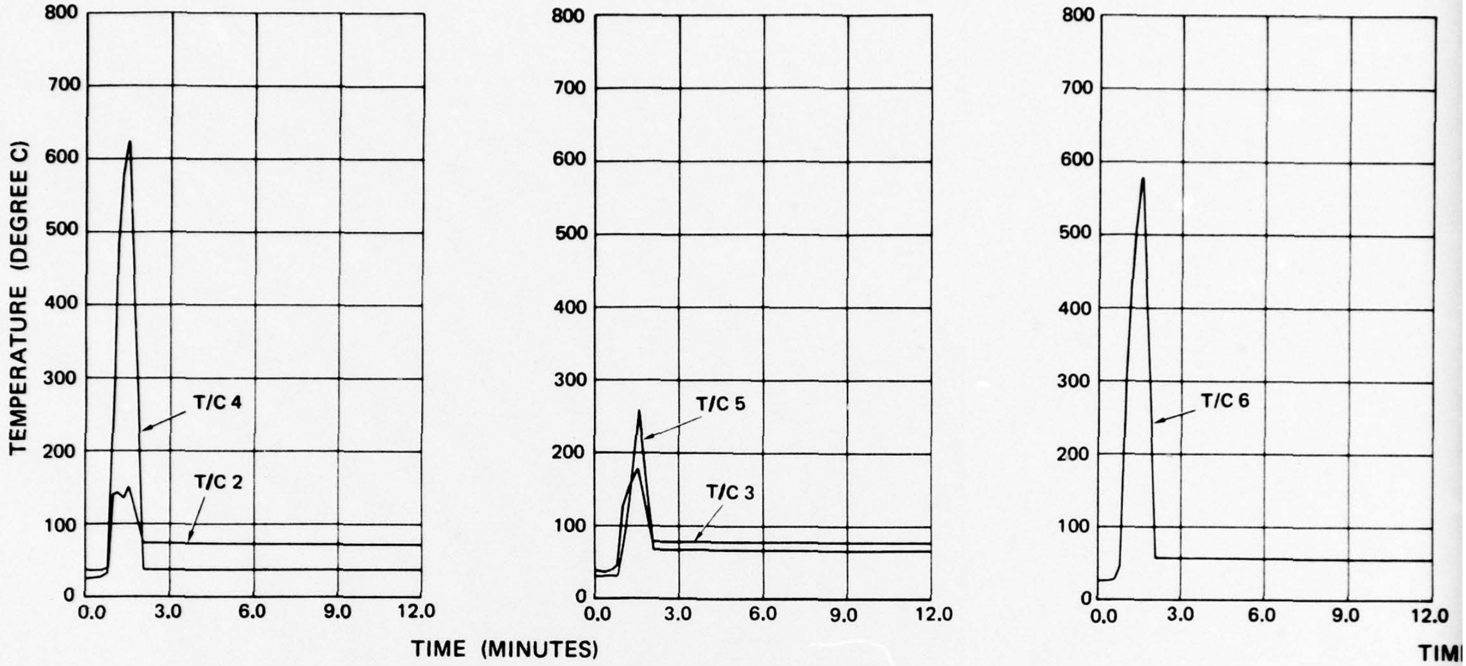
EXPANSION RATIO AS A FUNCTION OF CONTROL TIME

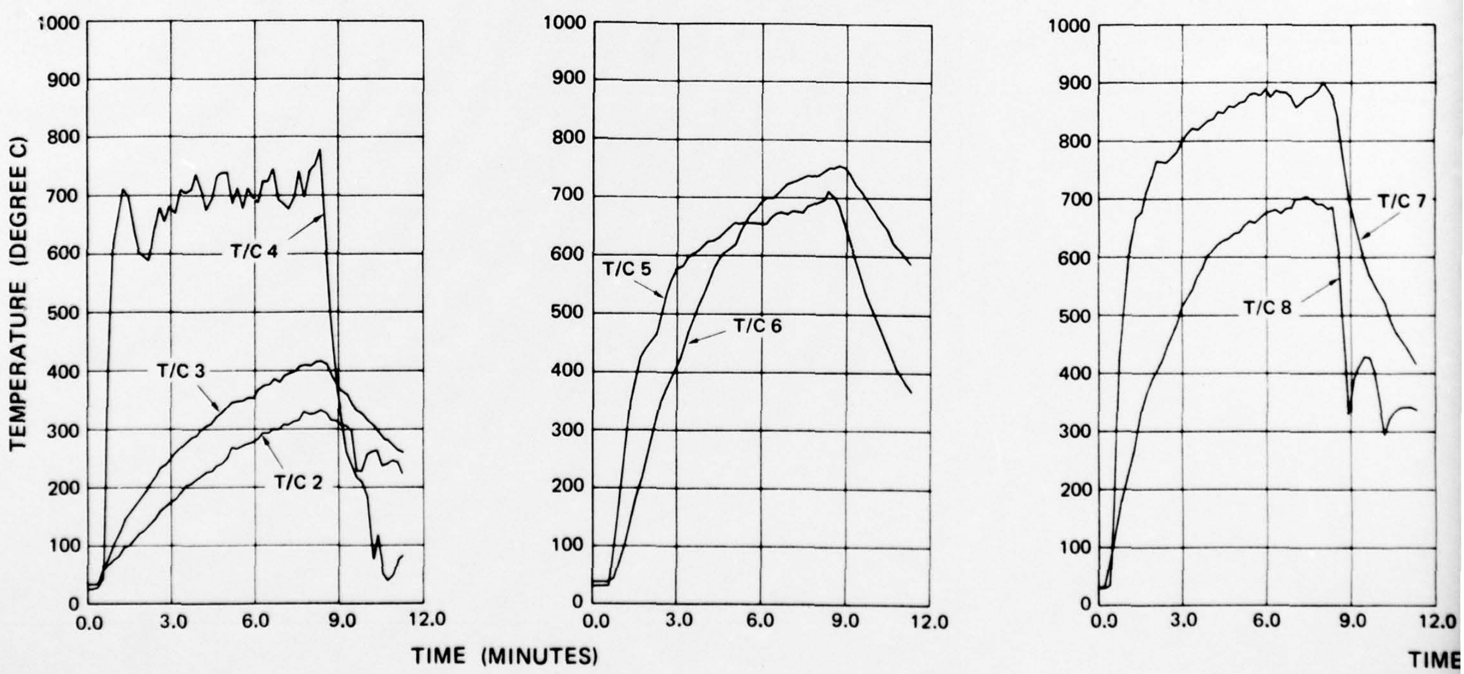
TABLE 5

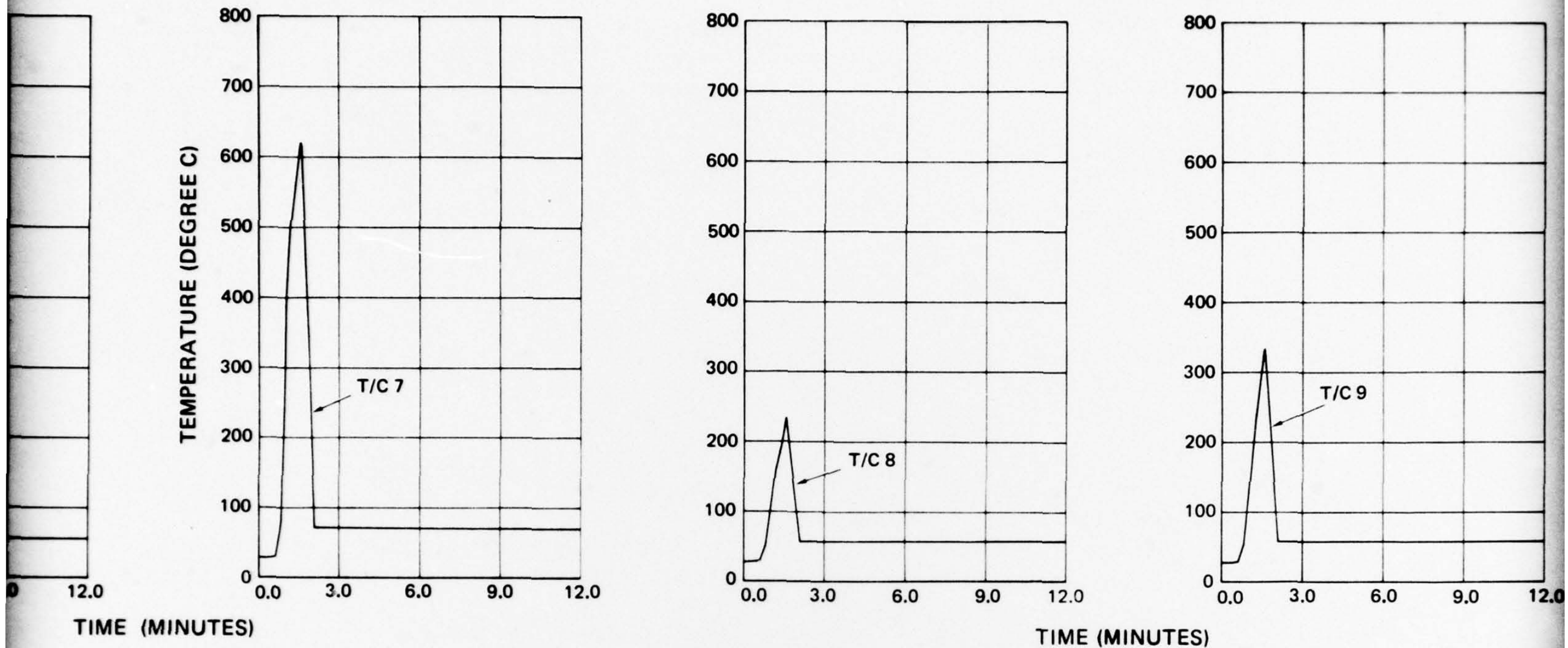
MAXIMUM TEMPERATURES DURING FIRE TESTS

TEST NUMBER	MAXIMUM TEMPERATURE (°C) ±5							
	T/C2	T/C3	T/C4	T/C5	T/C6	T/C7	T/C8	T/C9
17	550	640	670	630	720*	660	390	550
18	570	650	600	570	640	680*	400	530
19	500	610	490	450	610	630*	330	480
20	510	590	450	430	660	740*	320	450
21	630	680*	560	530	590	580	450	600
22	650*	590	570	570	490	530	390	540
23	780*	760	-	670	670	770	610	630
24	120	170	600	480	730	740*	380	530
24A	150	220	690	620	760	790*	470	570
25	-	-	-	-	-	660	-	-
25A	130	200	710	480	720	740*	350	480
26A	140	210	730	520	710	750*	360	480
27	160	210	670	480	750*	690	310	440
28	130	190	730	500	830*	740	310	440
29	160	220	650	450	690*	650	380	500
30	300	330	710*	560	540	660	400	520
31	150	230	710	600	680	730*	320	460
32	330	210	730	570	750	760*	350	480
33	330	420	840	730	520	900*	670	790
34	330	420	780	710	760	900*	700	810
35	490	460	-	490	210	530	360	530*
36	260	310	-	470	280	630*	320	490
37	740*	630	-	530	230	640	380	430
38	400	400	-	480	250	580*	320	470
38A	860*	800	-	530	310	690	600	720
39	540	460	-	430	250	640*	430	590
39A	840*	660	-	490	310	670	450	610

*Indicates Highest Temperature For Test


TEMPERATURE (DEGREE C)
800
700
600
500
400
300
200
100
0
T/C 4
T/C 2
T/C 5
T/C 3
T/C 6
0.0
3.0
6.0
9.0
12.0
TIME (MINUTES)


TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
T/C 4
T/C 3
T/C 2
T/C 5
T/C 6
T/C 7
T/C 8
0.0
3.0
6.0
9.0
12.0
TIME (MINUTES)



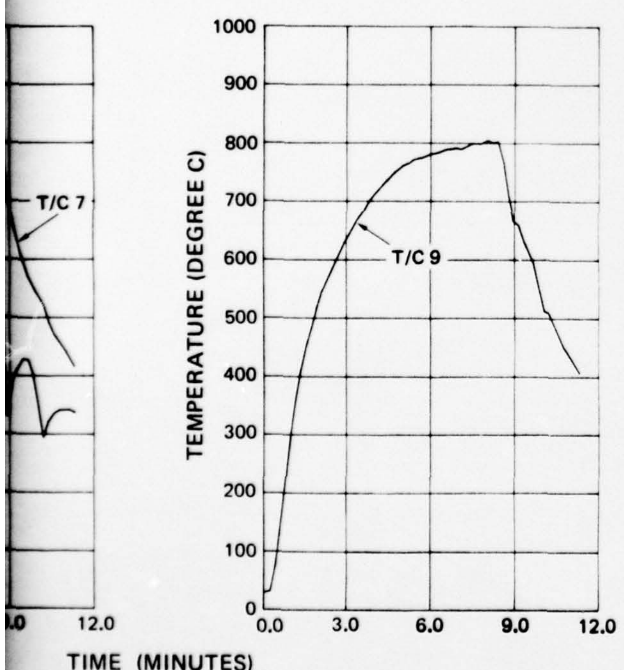


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FIGURE 18

TEMPERATURE TIME PLOTS FOR TESTS 26A (TOP ROW) AND 34 (BOTTOM ROW)

2

4.2.2 Burnback Resistance

The results of the burnback tests are displayed in Figure 19. This figure is a semi-logarithmic plot showing burnback area as a function of burnback time. While the limited number of data points do not completely justify the curves which are drawn through them, the curves are, however, indicative of the types of phenomenon which occurred during burnback. For instance, the upper left curves show that the burnback area increases quite rapidly and proceeds to total re-involvement in relative short periods of time. Test 24, 25, 25A, and 26 burned back the most rapidly. It was observed for these tests that the foam blanket did not provide complete coverage at the time the re-ignition source was exposed to the fuel. Test 20 had a somewhat slower burnback rate even though it did finally reach full involvement. The slower rate is due to the somewhat better foam blanket which remained over the fuel. The lower portion of Figure 19 depicts the case where the foam initially advances on the burnback re-ignition source and then for some period of time the re-ignition source continues to burn without gaining on the foam blanket. Finally, the re-ignition fire begins to advance on the blanket and the burnback increases to a rate which is similar to those displayed in the upper portion of the curve. While data was not taken for Tests 21, 22, 27 and 37 to full re-involvement, it is anticipated that they would have proceeded as in Test 38 to that point.

It should be noted that the results of the burnback tests with 6 percent protein foam do not appear in Figure 19 because they both successfully contained the re-ignition source. The burnback fire in Test 17 was extinguished in 0.1 minutes. This is believed to be due to the smaller initial burnback fire (12-inch diameter). This size fire is used in many of the reported tests[7,8] and appears to be one of the reasons why the literature does not differentiate between the burnback resistance of protein foam and AFFF.

The data shows that the proportioner/nozzle combination affects burnback in terms of the quality of the foam blanket produced; otherwise, burnback seems to be a function of the type of agent. Wind can easily negate the effects of a good foam nozzle by breaking up the foam blanket prior to/during extinguishment of the fire. The foam blanket provided by the Navy All Purpose nozzle on straight stream pattern was so poor at the time when burnback re-ignition would have occurred, that these tests were not conducted. The principal result of the burnback tests is that 6 percent protein foam very effectively stopped burnback and actually advances on the burnback re-ignition fire. The AFFF foam concentrates are not as effective at controlling burnback, and in fact, the fire advances on the AFFF foam blankets. The result for AFFF may be somewhat academic, however, because even in the worst burnback situation, the foam slowed the fire spread to such a degree that a firefighter would have time to observe the re-ignition and re-secure the area with application of additional foam.

5.0 CONCLUSIONS

The test program clearly shows that water fog nozzles as well as the mechanical foam nozzle can be used with the CG-6LP proportioner to effectively

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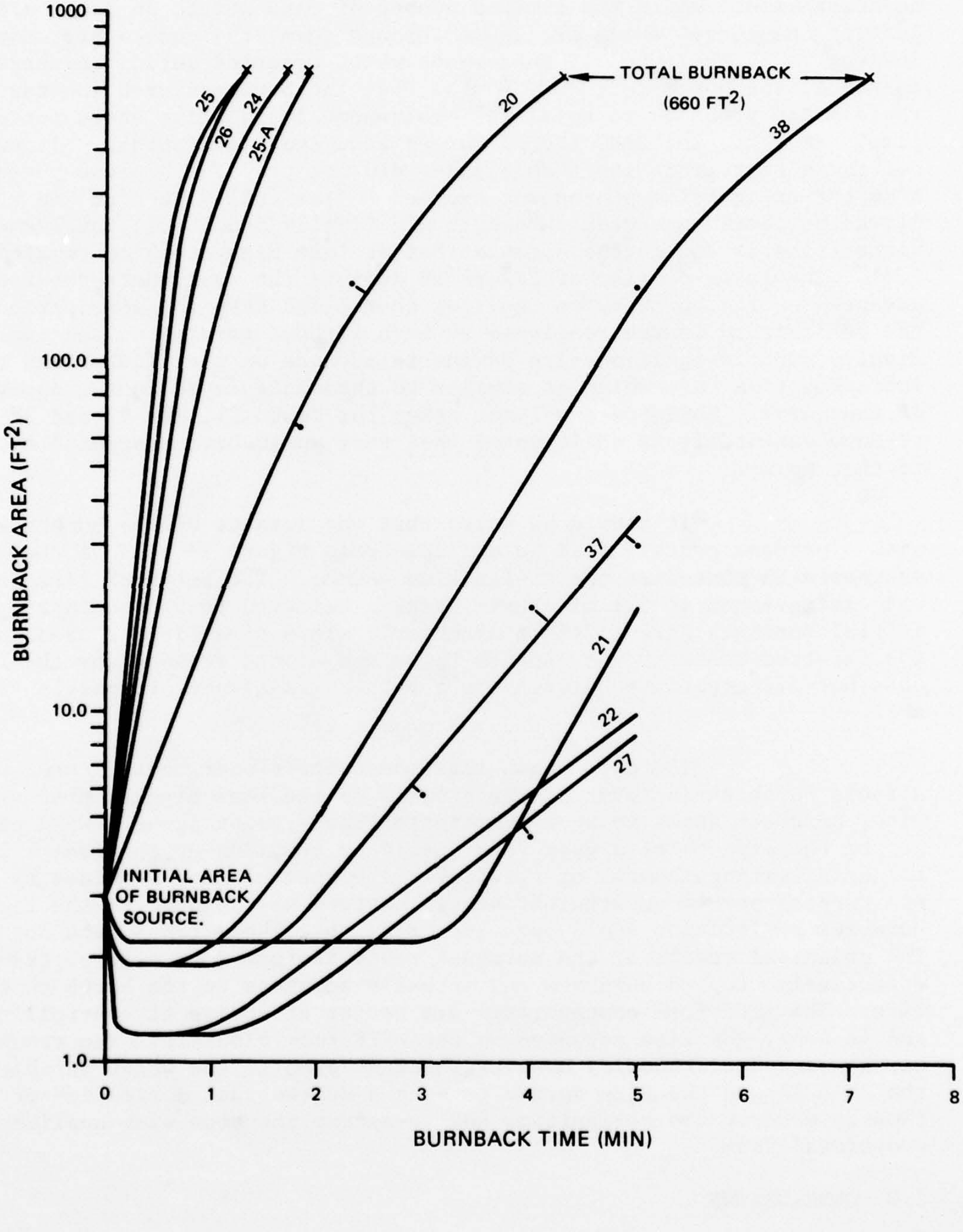

FIGURE 19

BURNBACK AREA AS A FUNCTION OF BURNBACK TIME

apply protein or AFFF foam solutions for the extinguishment of Class B fires. Specific conclusions follow.

1. The present Coast Guard in-line proportioner produces an acceptable proportioning rate when used with a 6 percent AFFF concentrate. If the decision is made to use the in-line proportioner with 6 percent AFFF concentrate, it would be advisable to modify the proportioner in a similar manner as described in Section 3.1.2 to bring the proportioning rate to 6 ± 0.5 percent rather than the 8+ percent which it currently produces. The modification design for converting the CG-6LP proportioner for use with 3 percent AFFF was very effective and could be simply manufactured and added to all proportioners currently in service.

2. The Navy All Purpose nozzle produces a very marginal AFFF foam blanket when used with the CG-6LP proportioner. The range from the nozzle, the expansion ratio, the drainage characteristics, the fire control and extinguishment times, and the burnback resistance of the blanket produced by this nozzle were inferior to the other nozzles evaluated.

3. There are commercial nozzles available which produce significantly better foam blankets when used with AFFF concentrates proportioned by the CG-6LP proportioner. The nozzles which used impinging holes in their baffles to enhance the foam expansion produced the best results. The mechanical foam nozzle is also superior to the Navy All Purpose nozzle for use with AFFF. The water fog nozzles, however, have the advantage of providing operator heat shield protection in a wide fog position and good fire control in a narrow fog position with remote cleanup enhanced in the straight stream position.

4. Non-aerated AFFF, as applied by the water fog nozzles evaluated, provides control times similar to the aerated AFFF applied by the mechanical foam nozzles.

5. The capabilities and characteristics of the optimum nozzles to be used with the CG-6LP proportioner are listed in Table 6. The SFL and 1715M nozzles produce essentially equivalent foam solutions while the mechanical foam nozzle is somewhat inferior due to its poor range and lack of fog patterns.

TABLE 6

CHARACTERISTICS OF OPTIMUM NOZZLES

CHARACTERISTIC CREATED BY NOZZLE AND CG-6LP PROPORTIONING 6% AFFF	NOZZLE TYPE		
	SFL @ 60 GPM	1715M @ 60 GPM	MFN
Flow (GPM)) @ 80 PSIG	44	42	41
Proportioning) @ 100 PSIG	48	46	44
6% AFFF) @ 125 PSIG	53	50	47
Proportioning Rate (%)	7.5	8	7
Straight Stream Expansion Ratio @ 100 PSIG	5	5.5	9
Range (FT) @ 100 PSIG	60	52	47
Patterns Available	Straight Stream Through Wide Fog		Straight Stream
Best 660 SQ FT Fire Control Time (SEC)	20	22	23

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